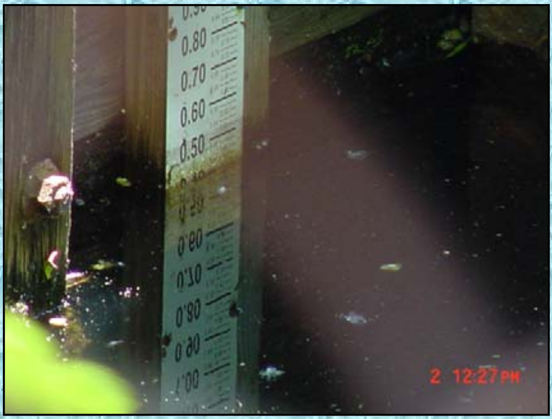
Executive Office of Environmental Affairs
Massachusetts Watershed Initiative

Mumford River Low Flow Study



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Executive Summary

Introduction

The Mumford River Basin, with a drainage area of 56.6 mi^2, is located in the south central part of Massachusetts (MA) and originates in the towns of Douglas and Sutton, MA. The river flows in a general easterly direction before emptying into the Blackstone River at Uxbridge, MA as shown in Figures E-1 and E-2.

Over the last few years citizens and local organizations such as the Blackstone River Watershed Association have expressed concern regarding low flow levels in the Mumford River. One local resident, Mr. Mike Yacino[1], who has lived on the Mumford River in Douglas for over 60 years, first noticed low flow problems on the Mumford River in the summer of 1999. It was reported that these conditions returned in the summers of 2000 and 2001 and that some sections of the river ceased to flow during these periods. The Executive Office of Environmental Affairs (EOEA) Watershed Initiative and the Blackstone River Watershed Team commissioned a study to investigate recurring low-flow observations in the Mumford River. The purpose of this study was to confirm if reported low flows were present during the past few summers and if so, to identify the potential causes of low flow conditions.

To help identify potential causes of low flows the following information was obtained or developed as part of this study.

- Water withdrawals registered and permitted under the Water Management Act (WMA) in Massachusetts were evaluated to determine the impact those withdrawals were having on streamflow (only water withdrawals greater than 100,000 gallons per day, GPD are subject to the WMA).
- The operations of numerous dams in the basin were investigated to determine if their operations were causing low flow conditions.
- Historic trends in land use were evaluated using available Mass-GIS coverages.
- The major hydrologic components of the watershed were examined. These parameters included: precipitation, streamflow, groundwater levels, water supply withdrawals and wastewater discharges.
- There is no long-term flow monitoring gage currently in operation on the Mumford River, making it difficult to evaluate long term flow trends[2]. To have a better grasp of current flow conditions, two staff gages were placed at key locations in the Mumford River and discharge rating curves were developed for each gage. The staff gages were read by volunteers to develop a database of flow conditions for the period June through September, 2003. This

[1] Mr. Yacino specifically noted low flow conditions on the bridge on Manchaug Road (near the St. Denis Cemetery) in Douglas. He also observed low flows emanating from Potter Road Dam. Mr. Yacino lives just before Soldiers Field in Douglas and observed low water levels in that area as well as through the center of Douglas down to the Gilboa Pond Dam. He also suggested that the impoundments to the left and right of Lackey Dam Road are also a great indicator of low flows given the weed proliferation especially in 2001 and 2002. He also observed stagnant water just before entering Whitinsville.

[2] There was a United States Geological Survey gage on the Mumford River in Douglas from 1939-51.

period happened to be one of the wetter summers in the last few years, thus it was difficult to duplicate low flow conditions in the summers of 1999-2002.

Summary of Key Study Findings and Results

Dams

There are approximately 37 dams located on tributaries and on the mainstem in the Mumford River Basin- this is a high number of dams relative to the drainage area size of 56.6 mi^2. In fact there are 13 mainstem dams over a distance of 13.5 miles- approximately one dam every river mile. The following summarizes our findings of dam operations:

- Most of the Mumford River mainstem dams are abandoned and ownership could not be determined. Based on our site reconnaissance, it appeared that these dams now function as run-of-river facilities. Most of these dams did not have low level outlets or gates that are typically used to regulate flow.

- Many dams are actively managed during the spring when flashboards are installed, and in the fall when flashboards are removed. Installing flashboards in the spring could artificially reduce the discharge to leakage while the impoundment fills (unless the facility has a low level gate). In the fall, flashboard removal could create artificially high flows. During the summer, when flows are traditionally the lowest, owners that could be contacted indicated that the facilities are not regulated, rather inflow equals outflow on a continuous basis. Typically, flashboard removal/installation was used for a variety of purposes including recreation use in the summer, weed control in the fall, and minor storage capacity during the spring runoff.

- Based on Gomez and Sullivan's research, dams that regulate flow on a daily and seasonal basis include: Manchaug and Whitin Reservoirs and Reservoir Nos. 6, 5, and 4 (total of 5 projects). These five reservoirs are seasonally operated by regulating discharges (see Figure E-2 for dam locations).

  Manchaug and Whitin Reservoirs collectively control a large portion of the Mumford River flow. These two reservoirs have significant storage capacity and are heavily regulated throughout the year. The reservoirs are actively managed; however, there is recognition that a balance is needed between recreational interests/lakeshore residents and downstream aquatic and assimilation needs. The reservoirs are drawn down, as needed, in the summer to maintain a continuous flow of 16 cubic feet per second (cfs) below Gilboa Dam, (see Figure E-2), which has a drainage area of approximately 31 mi^2. Thus, the minimum flow is equivalent to approximately 0.5 cfs per square mile of drainage area. The minimum flow is required for two purposes: a) to assimilate discharges from two National Pollutant Discharge Elimination Systems (NPDES) dischargers located further downstream on the Mumford River in East Douglas (see Figure E-2) and b) to provide sufficient flow for aquatic resources[3]. During the fall, the reservoirs are lowered further to create sufficient storage for

[3] Per IFGF's letter of October 31, 2003, the flow needed to assimilate their NPDES discharge is less than 16 cfs.

the spring freshet. In short, these two reservoirs artificially regulate flow by augmenting low flows in the summer and fall, and decreasing flows during the spring runoff.

The other three reservoirs, located in a series on Cook Allen Brook, are Reservoir Nos. 6, 5, and 4, which are considerably smaller than Manchaug and Whitin Reservoirs. The reservoirs are seasonally operated to maintain flow below Reservoir No. 4, the lowermost reservoir for public water supply withdrawals by Whitinsville Water Company. During the summer, when water demands typically peak, the reservoirs are drawn down to meet water supply demands.

Overall, it does not appear that dam operations are causing low flow conditions (with the exception of Reservoir Nos. 6, 5 and 4) in the Mumford River during the summer. In fact, Manchaug and Whitin Reservoirs supplement naturally low flow conditions by reducing impoundment levels in the summer to maintain 16 cfs below Gilboa Pond.

Water Withdrawals

There are four water withdrawals in the Mumford River Basin that are currently registered and/or permitted with the Massachusetts Department of Environmental Protection (MDEP) under the Water Management Act as shown in Figure E-2. They include the Whitinsville Water Company (WWC), Douglas Water Department (DWD), Interface Fabrics Group Finishing (IFGF) and the Whitinsville Golf Course (WGC). An analysis of 1998-2001 water withdrawal records was conducted. On an average annual basis, the major water users were WWC (70 %), followed by DWD (15%), IFGF (13%) and WGC (2%). The total average annual withdrawal for the period 1998-2001 was 656.7 million gallons (MG), which is equivalent to 1.8 million gallons per day (MGD) or 2.8 cfs annually. Average peak water usage typically occurs during July (68 MG) and June (66 MG), which is equivalent to approximately 2.2 MGD or 3.4 cfs during these months.

Water usage for WWC has increased by 25% from 1998 to 2001 and by 9% over a longer period 1996-2002[4]. If water use trends continue, WWC may exceed their allowable water withdrawal before February 2004. WWC supplies water to customers within the Mumford River Basin, and also sells water to the town of Northbridge, which is outside the Mumford River. Withdrawals are also occasionally trucked (2 out of the 4 years examined in this study) to the Milford, MA Power plant during summer months for cooling water use. A large portion of the WWC service territory has a sewer system with wastewater flowing to the Northbridge WWTP located on the Blackstone River. Infiltration and inflow to the sewer system is also carried out of the Mumford Basin.

DWD withdraws groundwater from four wells located within the Centerville and Riddle Brook subwatersheds of the Mumford River. DWD water usage has increased by 4% over the last four years. All of DWD's service territory is located in the Mumford River Basin. In addition, the East Douglas sewer system collects and discharges water only within the Mumford watershed. Thus, there is no out of basin water transfers- the only losses are attributable to evapotranspiration and evaporation.

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[4] Gomez and Sullivan's study focused on the period 1998-2001. WWC provided us with historical annual water usage from 1996-2002, which showed a percent increase of 9%.

IFGF withdrawals have steadily decreased over time, dropping by 27% between 1998 and 2001. They have implemented aggressive water conservation measures to help reduce water demands. In 2001, annual water withdrawals were 73 MG or 0.3 cfs (summer withdrawals were also around 0.3 cfs), which is well below their authorized annual withdrawal of 547 MG. According to IFGF, there is little water consumed in their processes- most water is returned to the Mumford River via their treatment plant discharge. On an annual basis there was a minor difference between their water withdrawal volume and the NPDES return volume in 2000 and 2001. However, on a monthly basis some water is consumed in IFGF's processing, but the exact amount could not be determined in this study.

WGC also withdraws water from the Mumford Basin during the golf season (generally late April through October). Their total withdrawal in 2001 was 14.2 MG over 180 days, with peak usage occurring in August of 3.3 MG (0.16 cfs). It is estimated that half of WGC's withdrawals are lost to evaporation and evapotranspiration.

Shown in Table E-1 is a summary of the estimated volume of water lost from the Mumford River Basin from these four WMA users.

Table E-1: Annual and Monthly Volumes of Water Lost to Evaporation or Transported out of the Mumford River Basin due to Water Withdrawals. Averages based on the period 1998-2001.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Average
TOTAL (in MGD)												
0.65	0.67	0.66	0.72	0.98	1.07	1.09	0.96	0.84	0.69	0.65	0.66	0.80
TOTAL (in cfs)												
1.00	1.04	1.02	1.12	1.51	1.66	1.68	1.48	1.29	1.07	1.01	1.02	1.24

Precipitation, Streamflow, and Upstream Storage Regulation

Historic and recent precipitation data were evaluated to determine if observed low flow conditions could also be a function of below-average precipitation levels. The analysis indicated that both the spring and summer of 1999 were one of the drier periods on record with virtually no precipitation occurring in June. Similarly, during July and August 2002, precipitation levels were also quite low. Summer precipitation levels in 2000 and 2001 were within average range. Based on this analysis, further evaluation in streamflow records was conducted.

Historically, a United States Geological Survey (USGS) streamflow gage was located on the Mumford River in Douglas (drainage area = 29.1 mi^2) from October 1, 1939 and September 30, 1951. An analysis of the historical flow data from this gage is presented in this report; however, to evaluate more recent flow trends in this area, we relied on a staff gage located below Gilboa Pond and operated by IFGF (although the accuracy of the gage may be questionable). The approximate drainage area of the staff gage is 31 mi^2, slightly larger than the retired USGS gage site. According to IFGF, the gage is calibrated every five years and is accurate up to 50 cfs, while flows between 50-100 cfs are estimated by IFGF. Flows are recorded daily, based on instantaneous measurements.

IFGF also provided 1999-2002 daily water level recordings at Manchaug and Whitin Reservoirs. Within the report are numerous plots depicting the relationship between precipitation, streamflow and water levels at Manchaug and Whitin Reservoirs for common periods of record. A few key observations could be gleaned from the study as follows.

- In most instances, after a precipitation event streamflow increased as expected.
- There were instances where the IFGF staff gage flows remained constant over several months of the summer, although there were many precipitation events during the same period.
- During most summer precipitation events, Manchaug and Whitin Reservoirs stored inflow, resulting in lower than natural flow conditions below the projects. The two facilities control 15.6 mi^2 of the drainage area at the IFGF staff gage (31 mi^2) or half of the drainage area.
- Based on the data provided by IFGF regarding gage flow records for the period 1999-2002, flows never dropped below 16 cfs, the minimum flow requirement.

In addition to the analysis of 1999-2002 data, the IFGF staff gage was supplemented with two additional staff gages placed upstream (at Potter Road Dam-22.6 mi^2) and downstream (Douglas Street Dam-48.3 mi^2) of the IFGF gage- see Figure E-3. Over the summer of 2003 staff gage rating curves were developed by obtaining a series of flow measurements that were related to staff gage heights. Volunteers read the two gages on a daily basis (instantaneously) between June 4 and September 15, 2003 and gage measurements were converted to flow via rating curves. In general, the summer of 2003 was considered wet relative to the summers of 1999-2002. There were instances during the summer of 2003 when measured flows at Potter Road and Douglas Bridge fell below 16 cfs, the minimum flow required below Gilboa Dam at the IFGF gage. The lowest measured flows were 14.6 and 14.7 cfs, at the Potter Road and Douglas Bridge gages, respectively. In short, there may have been instances when the true flow was below 16 cfs at the IFGF gage.

Discussion and Recommendations

General recommendations were developed to address issues that were encountered during the study process.

- It is recommended that the MDEP improve efforts to verify the accuracy of data reported on Public Water Supply Annual Statistical and Registered & Permitted Withdrawals Annual Reports as part of the Water Management Act. Some of the reported values were well outside the "normal" range.

- Hard copies of the Public Water Supply Annual Statistical Reports and Registered & Permitted Withdrawals Annual Reports were obtained by visiting the MDEP offices. The data from these reports were then keypunched into spreadsheets such that various graphs could be developed to evaluate the data. It would be extremely beneficial if water users were able to enter the data requested on the forms via an on-line reporting system. A computerized database would help in managing overall water uses and would reduce the time needed to keypunch data. This approach would also allow outlier values to be readily identified.

Dams

- In Gomez and Sullivan's limited research, we could not locate many of the dam owners and thus assumed that the dam was abandoned. It is recommended that further investigation into dam ownership be undertaken for two purposes. First, many of the dams have outlived their intended purpose, and may pose safety issues. Secondly, identifying the dam ownership would provide further information on the specific operation of the facility.

- There are numerous dams in the Mumford River Basin. The adverse impact of dams on fish, wildlife, wetlands, Threatened and Endangered species, water quality and other environmental resources is well documented in the literature. Given that many of the Mumford River dams have outlived their intended purpose, consideration should be given to potential dam removals.

- There is currently no gate rating curve that has been confirmed at the outlet of Manchaug and Whitin Reservoirs. Because the reservoirs highly regulate flow and control a major portion of the river flow, it is recommended that gages be placed just downstream of Manchaug and Whitin Reservoirs.

- It is recommended that IFGF strive to manage releases from Manchaug and Whitin Reservoirs to mimic the natural response to precipitation events. In many instances, flow at the staff gage remained constant even though precipitation events occurred. Although this recommendation is provided, it is recognized that recreation interests and homeowners around the lake will want to have a balance between summer recreation water levels and downstream aquatic resources.

- At many of the smaller dams flashboards are installed just after the spring runoff and removed in the fall. Once flashboards are affixed to the spillway crest, there may be several hours or days before the impoundment fills (depending on the impoundment size, contributing drainage area and height of the flashboards) to the flashboard crest. While the impoundment fills, no flow is conveyed below the dam unless a low level gate is opened. In some instances flow can be reduced to only leakage, which impacts downstream aquatic resources. It is recommended that a continuous minimum flow be provided below these dams when the flashboards are reinstalled

- It is recommended that all dams in the Mumford River Basin that regulate discharges should be operated to maintain continuous seasonal minimum flows throughout the year. Most dams under the State's jurisdiction are not necessarily required to maintain a continuous minimum flow. Absent any detailed studies, we recommend defaulting to at least the seasonal minimum flows set forth in the USFWS New England Regional Flow Policy as follows.

Period	Fall/Winter (Oct-Mar)	Spring (Apr)	Summer (May-Sept)
Flow per square mile	1.0 cfsm	4.0 cfsm for the entire applicable spawning and incubation periods	0.5 cfsm as derived from the median August Flow

Maintaining continuous seasonal minimum flows will help ensure that aquatic resources in the riverine reaches below the dams are protected. Obviously, for Manchaug and Whitin Reservoirs these flow recommendations could result in lowering the impoundments in the summer, which could create issues with homeowners, camps and summer recreation interests. Lowering the impoundments in the summer could also have similar environmental impacts on the littoral zone which could become dewatered. Thus, some negotiation of summer flows may be required for Manchaug and Whitin Reservoirs.

- Aldrich Pond, which is part of the Sutton Falls Campground, is located on a tributary to Manchaug Reservoir. A local resident indicated that in 2002, algae and other pollutants were discharged from Aldrich Pond into Manchaug Reservoir at the conclusion of the camping season when the gate was opened to lower the pond level. There is concern that a large influx of pollutants compromised the water quality of Manchaug Reservoir. Testing by Lycott Associates reportedly indicated that large amounts of phosphorus enter Manchaug Reservoir from Sutton Falls Dam. Large quantities of watermeal were also detected by the MA Department of Environmental Protection. It is recommended that the source causing pollutants to enter the stream system be evaluated and controlled. It is also recommended that the need for regular fall drawdowns be demonstrated.

Water Supplies

- There is no method to accurately track the amount of water transferred out of basin. More accurate information is needed on the amount of water leaving the Mumford River Basin prior to its confluence with the Blackstone River in Uxbridge.

- It is recommended that WWC and DWD take measures to further conserve water. This will require increased public outreach and education to end-users of the need for water conservation, particularly during critical low flow periods.

- Most low flow events occur in the summer when water supply demands are the highest, resulting in even greater stress on already low flowing rivers. For WWC and DWD, the ratio of peak demand to average daily demand was computed to determine the magnitude of summer usage. The peak factors were 1.74 for WWC and 1.90 for DWD. Through aggressive water conservation measures and public outreach, WWC and DWD should strive to limit this ratio to 1.5, as well as cap gallons per capita day (gpcd) use to 65. In addition, DWD should limit unaccounted for water to 10% or less if possible. Leak detection surveys and repairs should be conducted on an annual basis, if possible.

- It is recommended that WWC and DWD project future water supply needs in the years 2005, 2010 and 2020 based on population growth. The Commonwealth of Massachusetts' methods for forecasting future demand should be implemented for these suppliers. The concern is that water withdrawals will continue to increase, resulting in even greater stress on the Mumford River flows and tributaries. In the case of WWC, a portion of future withdrawals will likely continue to be transferred to the Northbridge WWTP for treatment. In the case of DWD, it is unknown if the East Douglas WWTP could absorb the projected increase in water use. By forecasting future usage, the town of Douglas can plan in advance any potential upgrades to their WWTP to handle future loads.

- It is recommended that trucking water from Meadow Pond to the Milford, MA Power plant be discontinued as it results in a direct loss of water from the Mumford River Basin during the low flow summer months

- The Whitinsville Golf Club does not have any water conservation policy in place. It is recommended that a water conservation plan or drought management plan be developed in consultation with the state. At the very least, it is recommended that golf course irrigation occur during the evening or early morning when evaporation is the lowest. In addition, during critically dry periods, it is recommended that watering be localized to only putting greens.

- IFGF has taken great strides to reduce water consumption. It is recommended that IFGF continue their efforts to reduce water consumption in the future.

Flow

- Water withdrawals contribute to low flows, as do the operation of some dams. In addition, during the summers of 1999 and 2002 precipitation levels were low, resulting in less streamflow.

- Based on the study findings, extremely low flows on the Mumford River in 1998-2001 could not be verified by our findings. In fact, without the flow augmentation provided by Whitin and Manchaug Reservoirs, summer flows would be even lower- closer to natural conditions. The USGS Streamstats[5] analysis indicated that under an unregulated river system Mumford River flows would be well below current regulated levels in the summer. The August median flow based on the retired USGS gage flow data was 23 cfs (0.79 cfsm) as compared to 5 cfs (0.17 cfsm) based on Streamstats. Relative to unregulated rivers in New England, the regulated August median flow (23 cfs) is considered high. In addition, although the IFGF gage requires recalibration, the minimum flow requirement since 1986 is 16 cfs below Gilboa Pond, which is roughly 0.5 cfsm- this is equivalent to the USFWS Aquatic Base Flow.

- There are times when the flows measured at the IFGF staff gage are not balanced with flow measurements and readings at Potter Road Dam and Douglas Dam. In some instances, the

[5] Streamstats is a model developed by the US Geological Survey that estimates unregulated flow statistics for a river basin.

flows were greater at Potter Road Dam as compared to the IFGF gage even though Potter Road is upstream. It is recommended that the IFGF gage be recalibrated and relocated to improve the accuracy of flow readings.

Although not highly recommended, if there remains a concern regarding low flows caused by regulation then additional flow monitoring may be implemented. Much of our analysis of pre-2003 data was based on the IFGF staff gage, which may be inaccurate at times. Currently, three staff gages are available, but they must be read manually to obtain instantaneously flow levels. In addition, two of the gages installed as part of this study were read by volunteers, which have been discontinued. Since rating curves have already been developed for these three staff gages, continuous water level recorders could be placed at all three sites and river stages could be converted to flow via the rating curves. Having long-term flow data for these three stations would help in evaluating flow trends and compliance with the 16 cfs release requirement. In addition, flow data in unregulated subwatersheds would provide baseline conditions for comparison purposes.

Development

- To help limit the amount of runoff entering stormwater systems, homeowners should be encouraged to utilize cisterns and rain barrels to collect and store rainwater for outdoor use.

- Between 1971 and 1999, residential land use in the Mumford River Basin increased by 7.9%, while forested land decreased by 8.6%. Development in the basin will impact the timing and magnitude of Mumford River streamflows. To limit the impact of future development, it is recommended that local planning boards carefully scrutinize new applications for large-scale developments (i.e., large subdivisions, golf courses, etc.). Planning Boards may wish to consider implementing a water bank or otherwise mandate mitigation measures to off-set the impacts of future developments to assure these do not place further demands on the water systems and exacerbate low-flow conditions.

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Acronyms and Conversions

<u>Acronyms:</u>

ABF	Aquatic Base Flow
cfs	cubic feet per second
cfsm	cubic feet per second per square mile of drainage area
COE	United States Army Corps of Engineers
DMR	Discharge Monitoring Report
DWD	Douglas Water Department
EOEA	Executive Office of Environmental Affairs
EPA	Environmental Protection Agency
gpcd	gallons per capita day
GIS	Geographic Information System
GPD	gallons per day
GPS	Global Positioning System
IFGF	Interface Fabrics Group Finishing, Inc.
IHA	Indicators of Hydrologic Alteration
MassGIS	Massachusetts Geographic Information System
MDCR	Massachusetts Department of Conservation and Recreation
MDEM	Massachusetts Department of Environmental Management
MDEP	Massachusetts Department of Environmental Protection
MDFW	Massachusetts Department of Fisheries and Wildlife
MG	million gallons
MGD	million gallons per day
MGM	million gallons per month
MGY	million gallons per year
MODS	Massachusetts Office of Dam Safety
msl	mean sea level
NPDES	National Pollutant Discharge Elimination System
PMF	Probable Maximum Flood
PWSASR	Public Water Supply Annual Statistical Report
UAW	Unaccounted for Water
USGS	United States Geological Survey
WWTP	Wastewater Treatment Plant
WMA	Water Management Act
WGC	Whitinsville Golf Club
WWC	Whitinsville Water Company

<u>Conversions</u>

1 MGD=1.547 cfs
1 MGD= 1,000,000 GPD
1 acre= 43,560 square feet
1 mi^2= 640 acres

Glossary of Terms

Aquifer: A geologic formation that contains sufficient saturated permeable material to yield significant quantities of water to wells and springs.

Base Flow: The sustained dry-weather flow of water in a stream.

Bedrock: General term for solid rock that underlies soil or other unconsolidated material.

cfs (cubic feet per second) : The flow rate or discharge equal to one cubic foot (of water, usually) per second. This rate is equivalent to approximately 7.48 gallons per second. This is also referred to as a second-foot.

cfs-day : The volume of water discharged in twenty four hours, with a flow of one cubic foot per second is widely used; 1 cfs-day is 24 x 60 x 60 = 86,000 cubic feet, 1.983471 acre-feet, or 646,317 gallons. The average flow in cubic feet per second for any time period is the volume of flow in cfs-days.

Consumptive Use: Water removed from the immediate aquatic environment through evaporation, transpiration, human consumption, agriculture, industry, etc.

Discharge: the volume of water that passes through a given cross section per unit time. Discharge is commonly measured in cubic feet per second (cfs) or cubic meters per second (cms). It is also referred to as *flow*.

Evaporation: The physical process of transforming a liquid into a gas.

Evapotranspiration: The process by which the earth's surface or soil loses moisture by evaporation of water and by transpiration from plants; the volume of water lost in this process.

Exceedence probability: hydrologically, the probability that an event selected at random will exceed a specified magnitude.

Flow Duration Curve: A cumulative frequency curve that shows the percentage of time that specified discharges are equaled or exceeded.

Hydrograph: a description of flow versus time or a description of stage versus time.

Hydrology: the study of water. Hydrology generally focuses on the distribution of water and interaction with the land surface and underlying soils and rocks.

Instream use: The use of water that does not require withdrawal or diversion from its natural watercourse; for example, the use of water for navigation, recreation, and support of fish and wildlife.

Interbasin Transfer: The physical transfer of water from one watershed to another.

Peak flow: the point of the hydrograph that has the highest flow.

Pulsing flow: the artificial increase and decrease of flow that typically follows a daily pattern.

Rating curve: the relationship between stage and discharge.

Reach: a segment of a stream channel.

Recurrence Interval: The average amount of time between events of a given magnitude. For example, there is a 1% chance that a 100- year flood will occur in any given year.

Reservoir: A manmade facility for the storage, regulation and controlled release of water.

Reservoir Surface Area: The surface area of a reservoir when filled to the normal pool or water level.

Reservoir Volume: The volume of a reservoir when filled to normal pool or water level.

Runoff: That part of precipitation that flows toward the streams on the surface of the ground or within the ground. Runoff is composed of baseflow and surface runoff.

Run-of-River Operation: A reservoir is operated as a run-of-river facility when reservoir inflow instantaneously equals reservoir outflow. There is no change in the timing or magnitude of reservoir inflow or outflow.

River Gage: A device for measuring the river stage, via a rating curve, river flow.

Stormwater Discharge: Precipitation that does not infiltrate into the ground or evaporate due to impervious land surfaces but instead flows onto adjacent land or water areas and is routed into drain/sewer systems.

Transpiration: Water returned to the atmosphere resulting from the leaves of plants.

U.S. Geological Survey (USGS): The Federal Agency chartered in 1879 by congress to classify public lands, and to examine the geologic structure, mineral resources, and products of the national domain. As part of its mission, the USGS provides information and data on the Nation's rivers and streams that are useful for mitigation of hazards associated with floods and droughts.

Watershed: an area characterized by all direct runoff being conveyed to the same outlet. Similar terms include *basin*, *subwatershed*, *drainage basin*, *catchment*, and *catch basin*.

Water Year: The USGS typically reports surface water data in terms of a water year, which is the 12-month period of October 1 through September 30. The water year is designated by the calendar year in which it ends and which includes 9 of the 12 months. Thus, the year ending September 30, 1946, is called the "1946 water year".

Wetland: An area that is regularly wet or flooded and has a water table that stands at or above the land surface for at least part of the year.

1.0 Introduction

The Mumford River Basin is located in the south central part of Massachusetts. The river originates in Douglas and Sutton, Massachusetts and flows in a general easterly direction before emptying into the Blackstone River at Uxbridge, MA. Shown in Figure 1.0-1 is the general location of the basin relative to the surrounding watersheds. The watershed has a drainage area of approximately 56.6 square miles (mi^2).

Over the last few years citizens and local organizations such as the Blackstone River Watershed Association have expressed concern regarding low flow levels in the Mumford River. One local resident, Mr. Mike Yacino, who has lived on the Mumford River in Douglas for over 60 years, first noticed abnormally low flow conditions on the Mumford River in the summer of 1999[6]. These conditions returned in the summers of 2000 and 2001 and it was reported that some sections of the river ceased to flow during these periods. Having heard these concerns and others, the Executive Office of Environmental Affairs (EOEA) Watershed Initiative Blackstone River Watershed Team commissioned a study to investigate recurring low-flow incidences in the Mumford River. This study strives to pin-point potential causes of low flow and makes short and long term recommendations to improve conditions.

To help identify potential causes of low flows the following information was obtained or developed as part of this study.

- Water withdrawals registered and permitted under the Water Management Act (WMA) in Massachusetts were evaluated to determine the impact of withdrawals, if any, on streamflow. The study analyzed the annual and seasonal water use trends including the timing and magnitude of peak water demand for the period 1998-2001. Emphasis was placed on evaluating water withdrawals during the summer, when river flows are typically the lowest. Daily precipitation levels during the last few summers were also evaluated in relation to water usage to determine any trends or relationships between these variables. As a general rule, when precipitation is low in the summer, water usage tends to increase due to lawn watering if no outdoor water use ban is implemented.

- Information was gathered on all permitted wastewater and industrial discharges in the basin. Of the four Water Management Act water withdrawers in the Mumford River Basin, most discharge wastewater or industrial water back to the basin (after evaporative and other losses occur). A portion of one water supplier's water distribution network system is serviced by a wastewater collection system. The wastewater network transports wastewater and infiltration/inflow to a wastewater treatment plant located outside the Mumford River Basin, resulting in a loss of water from the basin.

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[6] Mr. Yacino specifically noted low flow conditions on the bridge on Manchaug Road (near the St. Denis Cemetery) in Douglas. He also observed low flows emanating from Potter Road Dam. Mr. Yacino lives just before Soldiers Field in Douglas and observed low water levels in that area as well as through the center of Douglas down to the Gilboa Pond Dam. He also suggested that the impoundments to the left and right of Lackey Dam Road are also a great indicator of low flows given the weed proliferation especially in 2001 and 2002. He also observed stagnant water just before entering Whitinsville.

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- The operations of numerous dams in the basin were investigated. Most dams in the basin operate as true run-of-river facilities, where inflow instantaneously equals outflow, except during periods of removing or installing flashboards. There are two large seasonally operated reservoirs, Manchaug and Whitins Reservoirs (located in Sutton and Douglas), which regulate flows on the Mumford River to supply a minimum flow of 16 cfs near Douglas, MA. Dams were evaluated to determine if operations were causing low flow conditions.

- Historic trends in land use and wetland area changes were evaluated using available Mass-GIS coverages. As with many communities in Massachusetts there is continued growth and development leading to more housing and paved roads. Increased development creates impervious surfaces, which affect the timing and magnitude of runoff and groundwater recharge to the river.

- The major hydrologic components of the watershed were examined. These parameters include precipitation, streamflow, and groundwater levels, as well as water supply withdrawals and wastewater discharges.

- There is no long-term flow monitoring gage on the Mumford River, making it difficult to evaluate long term flow trends[7]. To have a better grasp of current and future flow conditions, two staff gages were placed at key locations in the Mumford River and discharge rating curves were developed for each gage. The staff gages were read by volunteers to develop a database of flow conditions during the summer 2003. Instantaneous flow data were recorded and evaluated in this report.

This study attempts to confirm the increased occurrence of unusually low flow conditions in the Mumford River during recent times. Once confirmed, the study evaluates potential causes of these low flow conditions, and attempts to determine their relative magnitude of impact. The potential causes evaluated include the following:

- Natural variations in the hydrologic cycle (i.e., precipitation patterns);
- Increasing water withdrawals for public water supply and industrial uses;
- Development (changes in land use and wetlands) within the Mumford River watershed;
- The operation of dams in the basin, which can influence the timing, magnitude and duration of flows in the Mumford River were evaluated;
- The export of wastewater and public water from the Mumford River Basin to the Blackstone River; and
- Other water withdrawals that are not subject to the Water Management Act.

The authors are very grateful to the numerous individuals who provided information or comments during the study. These individuals include Linda Marler (formerly MDEM, now Massachusetts Department of Conservation and Recreation), Russ Cohen (Massachusetts Riverways), Therese Beaudoin (MDEP), Linda Nelson (citizen), Wendy Porter (Interface

[7] There was a United States Geological Survey gage on the Mumford River in Douglas from 1939-51.

Fabrics Group Finishing), Jim Ouellet (Whitinsville Water Company), Dennis Croteau (Douglas Water Department) and Paul Lyons (IFGF). Paul Lyons provided a tremendous amount of information on the historical and current operation of the two larger storage reservoirs in the basin. These individuals were cooperative participants in this study and provided valuable input to support this project. They also greatly contributed to this report.

We also would like to thank Mike Yacino and Therese Beaudoin who both live in the basin for volunteering to read the staff gages. They visited the staff gages on a daily basis through sometimes awful weather conditions. Both of these citizens were key contributors to this study and we are sincerely grateful for their community service.

2.0 Mumford River Watershed Description and Physical Characteristics

The purpose of this section is to provide an overview of the Mumford River watershed characteristics and to describe various components of the river's course.

2.1 General Overview of the Mumford River Watershed

The Mumford River watershed lies in the south central part of Massachusetts and is a major tributary to the Blackstone River[8] as shown in Figure 1.0-1. Two maps were developed to assist in explaining the river's course and attributes of the basin. Shown in Figure 2.1-1 is a base map showing the locations of dams, impoundments, wastewater discharges, industrial discharges and water withdrawals. The second map (Figure 2.1-2) is a nodal diagram or schematic of the same base map, but it is not to scale.

The Mumford River originates in Manchaug (a village in Sutton), MA at the outlet of Manchaug Reservoir. Approximately 0.2 miles below Manchaug Dam, the river is impounded at Stevens Pond Dam, and then again at an unnamed dam (located near the intersection of Manchaug Road and Whitin Road-0.36 miles below Stevens Dam). Below the unnamed dam Dark Brook enters the Mumford River as it travels southeast where another unnamed tributary enters the mainstem. At the headwaters of the unnamed tributary are Crystal Lake[9] and Whitin[10] Reservoir, which are located in Douglas.

After the unnamed tributary enters the Mumford River, the Mumford flows south where it is impounded at Potter Road Dam. Approximately one mile below Potter Road Dam, near East Douglas, Riddle Brook and Centerville Brook drain into the Mumford River from the southern portion of the watershed. In the town of Douglas there are two dams in a series, separated by a short riverine section. The first dam is located near the Cook Street Bridge (referred to as another unnamed dam- no data is available on this dam), and just downstream near an apartment complex is the Old Mill Pond Dam.

Proceeding further downstream, the river turns north as the East Douglas wastewater treatment plant (WWTP) empties into the Mumford River. Below the WWTP the river is impounded by the Gilboa Pond Dam, which is owned by the Interface Fabrics Group Finishing, Inc (IFGF)[11]. IFGF has a National Pollutant Discharge Elimination System (NPDES) permit to discharge treated industrial effluent to the Mumford River just below Gilboa Dam.

Below Gilboa Dam two tributaries, Gilboa Brook and Dunleavy Brook drain into the Mumford River before the river becomes impounded at the Lackey Pond Dam, which was recently refurbished for the purposes of maintaining waterfowl habitat. A few hundred feet below Lackey Dam is Meadow Pond which is located on the mainstem. Draining directly into Meadow Pond are discharges from Whitins Pond Dam, which is a separate subbasin or tributary to the

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[8] The Blackstone River travels in a southerly direction through Massachusetts and Rhode Island before emptying into the Atlantic Ocean.
[9] Crystal Lake is listed as Badluck Pond on the topographic map. The dam is referred to as Cedar Street Pond dam.
[10] Also known as Wallis Reservoir and Hydro Projects North.
[11] Also known as Guilford Industries.

mainstem. There are two main tributaries draining into Whitins Pond, including Cook Allen Brook, which contains three reservoirs (Reservoir Nos.6, 5 and 4) that are managed by Whitinsville Water Company for water supply purposes. The second unnamed tributary drains from the north and passes through Carpenter Reservoir before discharging into Whitins Pond.

Within Meadow Pond there are two dams. One is managed by The Shop and the other is located behind the Northbridge town offices (Douglas Street Bridge passes just downstream of the second dam). From the outlet of the Douglas Street Bridge Dam the river turns south again and passes three more dams (Linwood Dam, Whitin Pond Dam and Caprons Pond Dam), before discharging into the Blackstone River in Uxbridge.

From the Mumford River's origin at the outlet of Manchaug Pond to the confluence with the Blackstone River there are 13 mainstem dams. The river travels approximately 13.5 miles over this same stretch and has a total drainage area of 56.6 mi^2- thus; there is approximately one dam every mile. There are roughly 37 dams impounding ponds, lakes and reservoirs in the Mumford River watershed, which collectively have a surface area of roughly 1,574 acres (2.5 sq mi) of the watershed (or roughly 4.4% of the total drainage basin). The most prominent waterbodies in the watershed that are over 50 acres in size include: Crystal Lake (94 acres[12]), Manchaug Reservoir (353 acres), Stevens Pond (83 acres), Whitin Reservoir (330 acres), Lackey Pond (120 acres), Meadow Pond (55 acres), Whitins Pond (135 acres), and Carpenter Reservoir (83 acres).

The major tributaries to the Mumford River include Dark Brook, Centerville Brook, Riddle Brook, Dunleavy Brook, Gilboa Brook, Purgatory Brook, Cook Allen Brook, Cold Spring Brook and Farrel Brook.

There are two state forests in the basin. The 4,640-acre Douglas State Forest borders Connecticut, Rhode Island and Massachusetts and offers a variety of recreational opportunities. Visitors can enjoy swimming, boating and fishing at Wallum Lake[13] and hiking/cross-country skiing on miles of woodland trails. Only a small portion of the Douglas State Forest is physically located in the Mumford River Basin. The other state park, Purgatory Chasm State Reservation (1,100 acres) includes the chasm, a unique natural landmark that runs for a quarter of a mile between granite walls rising as high as 70 feet. The Chasm is believed to have its origin in the sudden release of dammed-up glacial meltwater near the end of the last Ice Age, approximately 14,000 years ago (MDEM, Mass Parks website).

Parts or all of the following towns are located in the watershed: Douglas, Northbridge, Oxford, Sutton, Uxbridge and Webster. The basin is located entirely in Worcester County.

2.2 Basin Topography and River Slope

Shown in Figure 2.2-1 is a topographic relief map (in meters) of the Mumford River watershed. The river generally travels in an easterly direction as higher land elevations occur along the

[12] All acreages were obtained from the National Inventory of Dams, except Whitin and Manchaug Reservoirs. Acreages for these impoundments were obtained from a 1986 study by Acheron Engineering.
[13] Wallum Lake is located outside of the Mumford River Basin, but portions of the park are located in the Mumford River Basin.

western rim of the basin, with a maximum elevation of 277 meters (909 feet) at Wood Hill. The drainage area of the Mumford River above East Douglas has relatively steep terrain characteristic of the south central section of Massachusetts. The Mumford River has some of the steepest terrain in the entire Blackstone River basin (Acheron Engineering, 1986). The elevation drop between the Mumford River at the Manchaug Dam outlet (151 meters or 495 feet) and the confluence with the Blackstone River (61 meters or 200 feet) is approximately 295 feet. With a corresponding river length of 13.5 miles, the river slope is roughly 21.8 feet/mile. The river gradient is controlled by several natural ponds, and numerous man-made dams that create impounded conditions.

Generally, the basin shape is more round than narrow. Typically, watersheds with a narrow shape respond quickly to precipitation/runoff events as there is a shorter distance for flow to travel from the tributaries to the mainstem, whereas the opposite occurs with round shaped basins.

2.3 Surficial Geology

A surficial geology map of the Mumford River watershed is shown in Figure 2.3-1. The majority of the watershed is overlain by glacial till, particularly the western portion. Bedrock outcroppings in the watershed are common at higher elevations; however, glacial till typically covers the bedrock surface in most areas.

Low-lying areas are covered by glacial contact and meltwater deposits. These deposits typically consist of well sorted sand and gravel. In locations where these deposits form significant permeable layers, moderate to significant groundwater yields are common. These deposits occur principally in the eastern portion of the watershed along river corridors. Small deposits of floodplain alluvium also occur on flood terraces within the wider river valleys located in the watershed.

The Blackstone River watershed has smaller amounts of stratified drift and wetlands than many other Massachusetts watersheds. Without significant stratified drift deposits and wetland areas, rainstorms tend to cause flashy rises in streamflow and baseflows tend to be low because there is less water storage capacity available in aquifers.

2.4 Land Use

Land use mapping was available for the Mumford River watershed for the years 1971, 1985, and 1999 (MassGIS). The land use mapping has 21 land use classifications, which were interpreted by the Resource Mapping Project at the University of Massachusetts, Amherst from 1:25,000 aerial photography taken for each respective year. Table 2.4-1 depicts the 21 land use category classifications used for the mapping. Shown in Figure 2.4-1 is a basin map illustrating land use using the 1999 coverage.

Table 2.4-1: Land Use Category Classifications Used by MassGIS

Code	Category	Definition
1	Cropland	Intensive agriculture
2	Pasture	Extensive agriculture
3	Forest	Forest
4	Wetland	Nonforested freshwater wetland
5	Mining	Sand; gravel & rock
6	Open Land	Abandoned agriculture; power lines; areas of no vegetation
7	Participation Recreation	Golf; tennis; Playgrounds; skiing
8	Spectator Recreation	Stadiums; racetracks; Fairgrounds; drive-ins
9	Water Based Recreation	Beaches; marinas; Swimming pools
10	Residential	Multi-family
11	Residential	Smaller than 1/4 acre lots
12	Residential	1/4 - 1/2 acre lots
13	Residential	Larger than 1/2 acre lots
14	Salt Wetland	Salt marsh
15	Commercial	General urban; shopping center
16	Industrial	Light & heavy industry
17	Urban Open	Parks; cemeteries; public & institutional greenspace; also vacant undeveloped land
18	Transportation	Airports; docks; divided highway; freight; storage; railroads
19	Waste Disposal	Landfills; sewage lagoons
20	Water	Fresh water; coastal embayment
21	Woody Perennial	Orchard; nursery; cranberry bog

Land use in the Mumford River basin in 1971 and 1999 is shown as pie charts in Figures 2.4-2 and 2.4-3, respectively. Based on 1971 land use mapping, 73% of the watershed was forested, whereas in 1999 this dropped to 64.4%. The next largest land use is residential representing 8.6% in 1971 and increasing to 16.5% in 1999. Table 2.4-2 shows a detailed breakdown of land use in the Mumford River watershed (56.6 mi^2) for the years 1971, 1985, and 1999. Also, Figure 2.4-4 illustrates the relative land use changes for the various category classifications using 1971 as the base year. The residential (codes 10 thru 13) and recreation (codes 7 thru 9) categories have been combined to better illustrate trends.

Table 2.4-2: Land Use Distribution for the Mumford River Watershed (56.6 square miles)

Category	1971	1985	1999
Cropland	7.0%	6.6%	5.4%
Pasture	1.3%	1.2%	0.8%
Forest	**73.0%**	**69.0%**	**64.4%**
Wetland	1.1%	1.1%	1.1%
Mining	0.5%	0.7%	0.7%
Open Land	1.4%	1.6%	2.2%
Recreation	0.5%	0.5%	0.9%
Residential	**8.6%**	**11.5%**	**16.5%**
Commercial	0.4%	0.4%	0.5%
Industrial	0.3%	0.3%	0.5%
Urban Open	0.6%	0.7%	0.9%
Transportation	0.2%	1.1%	1.1%
Waste Disposal	0.0%	0.1%	0.1%
Water	4.7%	4.7%	4.7%
Woody Perennial	0.3%	0.3%	0.2%

Source: Mass-GIS

Overall for the 1971-1999 period, there appears to be a significant increase in residential land use (7.9%) and a corresponding decrease in forest land (-8.6%) within the Mumford River watershed. In addition, the amount of agricultural land use (cropland -1.6% and pasture -0.5%) also decreased to a lesser degree. It is also interesting to note that between 1971 and 1999 the wetland distribution has remained the same.

Discussed later in this report is a general summary of how urbanization and the creation of impervious surfaces in the basin can affect base flow conditions in the basin over time. In general, impervious surfaces result in quicker runoff and less time for runoff to naturally infiltrate to the groundwater and replenish base flow during the summer.

The watershed encompasses all or part of six municipalities, which support a population of approximately 69,400 people. Table 2.4-3 illustrates the Year 2000 and 1990 census totals for each entire community, as well as the percent of each community's land area within the watershed. The major population centers within the watershed are concentrated in village centers within Northbridge, Uxbridge, and Douglas.

Table 2.4-3: Population for Municipalities Located in All or Part of the Mumford River Watershed

Community	Percent of Community in Watershed	Total Population (1990)	Total Population (2000)	% Increase relative to 1990
Douglas	55.9%	5,438	7,045	29.6%
Northbridge	41.8%	13,371	13,182	-1.4%
Oxford	3.5%	12,588	13,352	6.1%
Sutton	54.4%	6,824	8,250	10.9%
Uxbridge	26.9%	10,415	11,156	7.1%
Webster	0.9%	16,196	16,415	1.4%
Total		64,832	69,400	7.0% (4,568 people)

The population in the watershed has grown by 7% from 1990 to 2000. The greatest population increases on a percentage basis occurred in Douglas and Sutton. Additional residential communities and subdivisions have been constructed during this period, which has created additional impervious surfaces. As described later annual water withdrawals from the Douglas Water Department and Whitinsville Water Company have been steadily increasing from 1998 to 2001.

2.5 Climate

Precipitation is an important factor when considering the cause of low flow conditions. Summer rainfall has a direct correlation on streamflow, as well as an indirect effect; the lack of rainfall can result in increased water usage (and hence further depletion of base streamflow). During periods of little to no summer precipitation, lawn watering occurs (by using public or private water supplies), resulting in greater stress on surface water resources. In this section, general information on historic air temperature and precipitation is provided. Later in the report, the relationship between water usage and precipitation is evaluated.

The average annual air temperature in the basin is 48 °F for the period 1959-2000 based on an air temperature gage at Buffumville Lake, near Oxford, MA. Monthly mean temperature during this period ranged from 22 °F in January to 70 °F in July. There are two long-term precipitation gages located near the Mumford River (the Whitinsville gage is in the watershed, the Uxbridge gage is just outside) watershed as shown in Figure 2.5-1. General statistics for each gage are shown in Table 2.5-1.

Table 2.5-1: Precipitation Statistics at Gages in the Mumford River Watershed

Parameter	Whitinsville 1872-2002	Uxbridge 1931-2002
Average Annual Precipitation	44.9 inches/year	46.5 inches/year
Maximum Annual Precipitation	60.5 inches in 1983	68.9 inches in 1972
Minimum Annual Precipitation	30.2 inches in 1965	28.4 inches in 1965
1998 Precipitation	55.2 inches	47.7 inches
1999 Precipitation	43.5 inches	41.6 inches
2000 Precipitation	46.9 inches	40.0 inches
2001 Precipitation	39.3 inches	43.1 inches
2002 Precipitation	48.0 inches	41.6 inches

Data at the two long-term precipitation gages (Whitinsville and Uxbridge) were used to determine the mean areal precipitation[14] for the Mumford River watershed for the common period of record, 1931-2002 Figure 2.5-2 depicts the average annual precipitation for the period 1931-2002 in relation to the long-term average. The last decade included years with lower than average annual precipitation. Further evaluation of precipitation during the 1990's and early 2000's is provided later in this report.

[14] Precipitation totals for the two gages were averaged.

2.6 History of Mumford River Basin

Like most of the waterways in the Blackstone Valley, the Mumford River has been significantly modified by the hand of man. Seen from the air today, what the Nipmuc Indians knew as a free flowing woodland trout stream appears to be a string of dams and ponds made by man in its quest for waterpower in the eighteenth, nineteenth and early twentieth centuries. Described below are excerpts from various historical documents regarding the use of the Mumford River for waterpower.

In the mid-1800s the river supplied water power for Douglas Axe Company, then the nation's largest supplier of axes, which dominated the economy of the town of Douglas for three decades.

There were also several textile manufacturing mills scattered along the Mumford River. Whitinsville is one of five mill villages that comprise the town of Northbridge. It was developed as an early mill village along the banks of the Mumford River during the beginning of the Industrial Revolution (1809). Whitinsville's mills reflect more than a century's evolution in two of New England's leading industries, textiles and textile machinery. Whitinsville, by the 1920's, housed the world's largest textile machine shop in the Whitin Machine Works. By the 1930's the mills were suffering as were all businesses from the great depression. World War II, as with most industries, provided a surge in production once again. However, the 1940's witnessed labor unrest and a move toward union activity which eventually brought an end to the mills by the 1950's. Today, the mills still stand and over the years have been renovated into apartment complexes, shopping places, and the homes of several large businesses. (Source: http://www.acol.com/nbridge/history)

In 1820, Capron Mills (located in Uxbridge on the Mumford River) introduced power loom weaving of woolen cloth in their factory on the Mumford River, the first of such looms ever constructed. In 1827, major industrial complexes such as the massive granite Crown and Eagle Mills assumed great economic importance. The Crown and Eagle boasted a large-scale water power system and clusters of worker's duplexes.

The Blackstone Canal, completed in 1828, facilitated the transport of agricultural goods, raw materials and finished products to all points between Worcester and Providence. Since Uxbridge was halfway between the two, it became an overnight stopping place for canal boats. The town's stone quarries produced the stone to rebuild Boston after the Great fire (1872) and during the Civil War several of the town's mills ran on 24-hour shifts to fill government orders. In the First World War the town's economy boomed again as the mills worked to produce khaki overcoat cloth for America, France and Italy. ~ quoted from the community profile
(Source: http://www.uxbridgeonline.com/history.htm)

As recently as the 1960s Douglas poured its raw sewage into the river. Below the center of Douglas, the Hayward and Hayward-Schuster woolen mills dumped huge quantities of acid, dyes, oil, and detergent into the river just below their dams. Despite the pollution the fish and wildlife struggled successfully to hold on. Brook trout still frequented the shadows in the tributaries. The Mumford River was dying until the conservation revolution of the last 30 years. The Hayward Woolen building is now an apartment complex whose prime properties overlook the old Hayward Dam. Interface Fabrics Group Finishing purchased both the Manchaug and Whitin Reservoir Dams, which regulate the river to produce a steady flow of water.

Many dams provided processing water or waterpower in the 1800's and early 1900's until water-dependent industry began to collapse. Today, there are numerous dams that impound the Mumford River and its tributaries that no longer serve a vital function and have outlived their initial purpose.

3.0 Dam and Project Operations

The Mumford River, like most watersheds in New England, has several dams that currently or historically were used for various purposes including water supply, industrial use, fire protection, hydropower and recreation. Most of the dams were constructed many years ago to provide water and power for the region's industrial growth. Many of these dams sit abandoned and do not serve any function. Mr. Jerzy Pietrzak of the Massachusetts Office of Dam Safety (MODS) was contacted to obtain information on the dams within the Mumford River Basin. Mr. Pietrzak provided a listing of dams in the Blackstone River drainage, which was cross referenced against the National Inventory of Dams[15]. Using this list and the Mass-GIS dam coverage, dams in the Mumford River Basin were identified. In addition, a reconnaissance survey of the Mumford River mainstem dams was conducted, resulting in the identification of three additional dams currently not shown on the Mass-GIS coverage. Based on the databases and our reconnaissance survey, there are approximately 37 dams located in the Mumford River Basin. General information on most dams (owner, structural height, year constructed, hazard classification, drainage area, etc) is provided in Appendix A of this document. As noted above, three dams are not shown on the Mass-GIS coverage or in the National Inventory of Dams, thus they are not included in the table in Appendix A. The location of all dams (including the three unnamed dams) is shown in Figure 3.0-1.

It is important to understand the current purpose, operation and function of some of the larger impoundments in the Mumford River Basin as they have a bearing on how river flow is regulated, and how aquatic resources and flow regimes below each project might be affected. For example, a hydropower facility may operate in a peaking mode where inflow is stored over several hours and then discharged during high electrical demand periods. This type of operation affects the timing and magnitude of river flow. This is just one example of how dam operations affect flow. Other forms of flow regulation may occur depending on the purpose and function of the dam/impoundment.

It is beyond the scope of this study to evaluate the operation and purpose of all 37 dams in the Mumford River Basin. The list of dams was narrowed to include all impoundments greater than 50 acres, as well as all mainstem dams regardless of their impoundment size. Emphasis was placed on this "short-list" of dams as they likely have the greatest ability to regulate flow conditions on major tributaries and on the Mumford River mainstem. A total of 19 dams fall under this short-list, of which 13 are located on the mainstem. Highlighted in Figure 3.0-2 are the dams that were evaluated in this study.

A few notes are worth mentioning regarding our research of the dams.

- As noted above a reconnaissance survey of the Mumford River mainstem dams was conducted on May 16, 2003 and photographs were taken. Many of the dams are well over a hundred years old and were used during the height of textile and axe manufacturing in the late 1800's and early 1900's. Today, many sit abandoned and do not appear to be actively managed.

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[15] The National Inventory of Dams includes summary information on all dams in the United States. The data is available on-line at the following Army Corps of Engineers website: http://crunch.tec.army.mil/nid/webpages/nid.cfm.

- When identified, dam owners were contacted to obtain information on how the facility is operated; however, ownership for some dams was unavailable and thus operational data was also unavailable. A significant effort was put forth to locate the dam owner. Inquiries were made with the Massachusetts Office of Dam Safety, other dam owners in the basin, town officials, and assessors' offices regarding ownership. Unfortunately, it was impossible to identify all dam owners, and thus no information was available on how some facilities are operated.
- As stated above, photographs of each dam on the Mumford River mainstem were collected. All of the photographs and a dam location map (topographic map on a metric scale) are shown in Appendix B of this document and are organized according to the sections below.
- Based upon our review, none of the dams on the Mumford River are currently used for hydropower generation.

3.1 Manchaug Reservoir and Dam/Whitin Reservoir and Dam

Manchaug and Whitin Reservoirs are discussed together in this section as both facilities are operated in a coordinated fashion by Interface Fabrics Group Finishing (IFGF). Pictures of both dams are shown in Figure B-1 and B-2 of Appendix B, respectively. These projects are sometimes referred to as Hydro Projects North (although no hydropower generation occurs at either site). Both facilities are comprised of an earthen dam with outlet control structures. The location of both dams is shown in Figure 3.0-2.

Basic information on both reservoirs is shown in Table 3.1-1.

Table 3.1-1: Statistics on Manchaug and Whitin Reservoirs

Reservoir	Drainage Area	Surface Area	Usable Storage	Maximum Storage
Manchaug	6.7 mi^2	353 acres	1,974 acre-ft	4,385 acre-feet
Whitin	8.9 mi^2	330 acres	3,122 acre-ft	4,132 acre-feet
Totals	15.6 mi^2	683 acres		

Source: Acheron Engineering, 1986

In February 1986, Hydro Projects North, Inc, acquired controlling interest in two reservoir companies, each of which owned a dam and related reservoir on the Mumford River. The company and related dams were:

- The Mumford River Reservoir Company- Whitin Dam
- The Manchaug Reservoir Corporation- Manchaug Dam

In 1986 both of these companies directed Hydro Projects North to carry out the active management of the reservoirs in accordance with a set of guidelines and goals. The current operating guidelines, as provided in a 1986 report by Acheron Engineering, follow:

- *Goal 1*: To provide as uniform a flow as possible in the Mumford River downstream of the reservoirs. Flows released from the reservoirs will be used to augment natural flows in the Mumford River for water supply, maintenance of aquatic fish and wildlife habitat and wastewater dilution.

- *Goal 2*: To provide, to the extent reasonably possible, storage capacity for runoff from unusually high precipitation and snowmelt events. Storage of high runoff or flood events shall be exercised during those periods that the reservoir is drawn down to accommodate Goal 1. At no time shall the goal of flood control supercede the requirements of Goal 1 or the necessity to protect the structural and operating integrity of the dam. Operation of the dam and use of the reservoir for flood control shall at all times be consistent with the Mumford River Emergency Action Plan.
- *Goal 3*: To provide as stable a water surface elevation as possible in the reservoir during the summer recreation season from June 1 to September 1 each year. Reasonable effort shall be made to maintain stable water levels in the reservoir, but at no time shall Goal 1 be compromised to accommodate stable water levels in the reservoir.

To better understand the operation of Manchaug and Whitin Reservoirs, IFGF provided daily instantaneous water elevation data from 1999-2002 as shown in Figure 3.1-1 and 3.1-2, respectively. As the figures depict, both projects are operated as seasonal storage reservoirs by reducing water levels in the fall and refilling during the spring freshet. At Manchaug, full pond elevation is 519.02 feet USGS (without flashboards), with the average maximum drawdown from 1999-2002 being roughly 513.76 feet (5.26 feet average drawdown). Thirty-seven (37) inch flashboards are affixed to the spillway crest in the early spring, raising the crest elevation to 522.10 feet. Flashboards are removed in the fall. Similarly, full pond elevation at Whitin Reservoir is 596.42 feet USGS (without flashboards), with the average maximum drawdown from 1999-2002 being roughly 590.53 feet (5.9 feet average drawdown). Flashboards (22.5 inches) are added to the spillway crest in the early spring raising the crest elevation to 598.29 feet. Flashboards are removed in the fall.

As Figure 3.1-1 and 3.1-2 show there is a target rule curve, showing a greater drawdown than either reservoir experienced from 1999-2002. The target rule curves were established in 1986 with the assistance of the US Army Corps of Engineers (Corps) and Massachusetts Office of Dam Safety to ensure structural integrity of the dams during peak spring runoff (Reference: Paul Lyons, IFGF). In short, this means that the State and the Corps want to manage water levels to prevent overtopping of the earthen dams, particularly during the spring runoff. According to IFGF, the Whitin Reservoir spillway is inadequately sized to safely pass half the probable maximum flood (PMF). This is not the case with Manchaug Dam.

IFGF obtains rainfall data and monitors weather forecasts to help manage both reservoirs. The extent of seasonal drawdown is dependent on snowpack and anticipated spring rains. IFGF lowers the reservoirs in the winter to store much of the spring runoff while striving for full capacity by June 1. A full pond by June 1 allows IFGF to manage flows during the dry summer months to achieve a minimum flow of 16 cfs (explained below) in Douglas while minimizing, to the extent possible, reservoir drawdown during the recreation season. Reservoir operations result in higher than natural flows in the summer, fall and portions of the winter, while reducing natural flows in the spring as impoundments fill.

Operation of Manchaug and Whitin Reservoirs requires a delicate balance between many competing water uses including recreation, shoreline home owners, wastewater assimilation, water quality, aquatic life and structural integrity of the dams. Both reservoir shorelines are scattered with homes, summer cottages, and camps, and there is a boat launch on both impoundments. The reservoirs are used for fishing, swimming, and other recreational purposes[16]. In addition to recreation needs, both reservoirs are managed to maintain a minimum flow of 16 cfs on the Mumford River just below Gilboa Pond in Douglas (see Figure 3.0-2). The minimum flow is provided for two purposes: a) to assimilate discharges from two National Pollutant Discharge Elimination Systems (NPDES) dischargers located further downstream on the Mumford River in East Douglas (see Figure 3.0-2) and b) to provide sufficient flow for aquatic resources. The two NPDES discharges include the East Douglas Wastewater Treatment Plant (WWTP) and IFGF's permitted discharge (which is located below Gilboa Pond). IFGF indicated that the flow needed to assimilate their NPDES discharge is less than 16 cfs

IFGF indicated that if water is released from storage to meet the required 16 cfs, both reservoirs are evenly regulated for equal water level reductions. There are no minimum flow requirements below Manchaug and Whitin Reservoirs. However, a review of gate opening records provided by IFGF for the period 1999-2002 indicates that the gates are never completely closed; some flow release is always maintained. No gate rating curve is available to relate the gate opening to discharge.

IFGF maintains a staff gage approximately 75 feet downstream of Gilboa Dam (in Douglas) to ensure compliance with the minimum flow requirement of 16 cfs. The river stage is recorded instantaneously once a day by an IFGF employee who visits the staff gage, and then converts the stage to flow via a rating curve. The staff gage is located near the retired United States Geological Survey (USGS) streamflow gage referred to as the Mumford River at East Douglas (Drainage Area= 29.1 mi^2)[17]. According to IFGF, their gage is calibrated every five years to ensure that the river stage versus flow relationship is accurate. It should be noted that the rating curve for the gage is effective for measuring flows up to 50 cfs, and IFGF estimates flows from 50 to 100 cfs. When flows exceed 100 cfs, IFGF does not estimate or measure the flow. Shown in Figure 3.1-3 are the 1999-2002 instantaneous daily flow readings. As the graph depicts, the IFGF data indicates flows below the Gilboa Dam remained at or above 16 cfs for the period examined. As described later in this document, the flows recorded at IFGF's staff gage appear to out of balance with flow measurements taken above and below IFGF's staff gage, thus the gage accuracy is questionable.

As noted above reservoir levels, particularly in the summer, are managed to maintain 16 cfs on the Mumford River in East Douglas by increasing reservoir discharges. To illustrate this point, Figures 3.1-4 through 3.1-7 show the 1999 through 2002 Manchaug Reservoir elevations and flows on the Mumford River below Gilboa Dam, respectively. Similarly, shown in Figures 3.1-8 through 3.1-11 are the 1999-2002 Whitin Reservoir elevations and same Mumford River flows,

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[16] IFGF indicated in their October 31, 2003 letter that greater detail on recreation use of the reservoirs is needed to present a more balanced description of water use. An evaluation of recreation use was beyond the scope of this study. However, it should be noted that there are several campgrounds, a water slide, and many waterfront homes along Manchaug and Whitin Reservoirs.

[17] This gage (No. 01111000) was active from 1939-51.

respectively. As the graphs show, when flows on the Mumford River in Douglas start to recede, discharges from Manchaug and Whitin Reservoirs are increased to augment flow conditions. In 1999, which represented a dry summer, flows on the Mumford River as recorded by IFGF at their gage, were maintained at 16 cfs for nearly the entire summer. Also, during the summer of 1999 both reservoir elevations were reduced more than the other years examined.

3.2 Sutton Falls Dam, Aldrich Pond (tributary to Manchaug Reservoir)

Sutton Falls Dam impounds Aldrich Mill Pond (9 acres), which is located at the Sutton Falls Campground. Although this impoundment is not greater than 50 acres and the dam is not on the Mumford River, it was included in the evaluation to highlight concerns raised by Linda Nelson, a local citizen. Ms. Nelson asserts that algae and pollutants (specifics unknown) in Aldrich Pond were discharged to Manchaug Reservoir at the conclusion of the 2002 camping season, which compromised the water quality and aesthetics of Manchaug Reservoir.

Sutton Falls Dam is the next dam upstream of Manchaug Reservoir as shown in Figure 3.0-2. The campground is open from April 15 to Columbus Day. Mr. Roger Gringass manages the campground and has operated the dam since 2002. The dam includes a sluice gate to lower water levels and a fixed concrete spillway crest laid over stone.

During the summer 2002, the sluice gate remained closed (except for leakage), while pond inflow was spilled over the dam- essentially the dam was operated in a true run-of-river fashion where inflow instantaneously equals outflow. At the conclusion of the camping season, the sluice gate was opened to lower the pond for purposes of controlling weeds and to remove excessive algae growth. Mr. Gringass indicated that it took between 3-5 days to lower the pond, while the sluice gate remained open until approximately January 2003 (Ref: Roger Gringass, Personal Communication, 2003). During January 2003, the sluice gate was closed to refill the pond. During the refill period, flow below the dam was reduced to leakage only.

As noted later, it is recommended that Sutton Falls Dam be operated in a true run-of-river manner year round. There appears to be a water quality issue in the watershed above Aldrich Mill Pond and by sluicing the algae and large nutrient load downstream, the problem shifts to Manchaug Reservoir. In addition, when Aldrich Mill Pond is refilling, flows below the dam are reduced to only leakage. It is recommended that if year-round run-of-river operations can not be mandated and the pond is still lowered annually, then a continuous minimum flow should be maintained while the pond refills.

Following the submittal of the Mumford River draft report, Ms. Nelson clarified that major pollutant discharges from Sutton Falls Dam can occur any time such as in the spring or summer if there are torrential rains. Ms. Nelson indicated that Lycott Associates detected large amounts of phosphorus being discharged into Manchaug Reservoir. In addition, the MDEP identified large amounts of watermeal (Wolffia Columbiana) in the lower cove.

3.3 Crystal Lake Dam (also known as Badluck Pond), Cedar Street Pond Dam, Tributary to Whitin Reservoir

Crystal Lake Dam, with a surface area of 94 acres, drains into Whitin Reservoir (a tributary to the Mumford River). According to the Douglas town assessor, the former owner passed away. The current owner could not be identified and thus it is unknown if the facility is actively managed.

3.4 Stevens Pond and Dam

Stevens Dam is located approximately 0.20 miles downstream of Manchaug Dam and the pond is used primarily for recreation. It has a surface area of 80 acres, storage capacity of 600 acre-feet and drainage area of 7.1 mi^2 (Source: National Inventory of Dams). The dam is owned and operated by the Town of Sutton. Shown in Figure B-3 are pictures of the dam.

The spillway crest elevation is 467.4 feet above mean sea level (msl) with the normal pool elevation at 470.15 feet (top of flashboards). Mr. Mark Brigham of the Town of Sutton provided basic information on how Stevens Dam is operated (Personal Communication, Mark Brigham, 2003). Normally in the fall a low level gate is opened to lower the impoundment elevation to just below the spillway crest. After the water elevation falls below the spillway crest, the flashboards are removed and the gate is closed, allowing water to spill over the dam. In the spring, the gate is reopened to allow the spring freshet to pass downstream. When the water elevation is below the spillway crest, the gate is closed, flashboards are reinstalled, and flows pass over the flashboards.

There are no minimum flow requirements below Stevens Dam. The dam is operated as a run-of-river facility, except during the periods in the fall and spring when flashboards are removed and reinstalled. Mr. Brigham provided the following information of gate operations over the last three years.

10/15/00 Open Gate 4 inches 10/19/00 Close Gate/Remove Flashboards 04/09/01 Open Gate 6 inches 04/13/01 Close Gate/Replace Flashboards	10/24/01 Open Gate 4 inches 10/29/01 Close Gate /Remove Flashboards 04/08/02 Open Gate 4 inches 04/12/02 Close Gate/Replace Flashboards
11/01/02 Open Gate 6 inches 11/08/02 Close Gate/Remove Flashboards 04/02/03 Open Gate 5 inches	

Mr. Brigham indicated that after the flashboards are replaced in the spring and the gate is closed there are days when there is no discharge from the dam, as inflow is stored. It was also noted that under exceptionally rare conditions (such as a hurricane) when flows are very high, the town may open the gate to limit the amount of water flowing over the flashboards (otherwise the gate remains closed at all times except to replace flashboards). In the recommendations section, it is suggested that a continuous minimum flow be provided below the dam when the gate is closed and the pond is refilling. The current dam operation reduces the discharge to leakage during the refill period.

3.5 Unnamed Dam on Mumford River

Although not shown in the Mass-GIS dam coverage, there is another dam on the Mumford River, located a short distance below Stevens Pond as shown in Figure B-4. This stone dam is located near the intersection of Manchaug Road and Whitin Road. The dam is quite old and does not appear to be actively managed. It is assumed that the dam functions as a run-of-river facility since the impoundment is small and the depth shallow. Given this, even if the facility was actively managed, the ability to modify the flow regime appears minimal.

3.6 Potter Road Dam (also known as Grays Pond)

Having talked with IFGF, the Town of Douglas assessor, and other groups in the basin, it appears that Potter Road Dam (located in Douglas) is also abandoned- ownership could not be identified. The Massachusetts Office of Dam Safety was contacted to identify the owner of the dam. Their archives indicate that Guilford Industries (now IFGF) owns the dam; however, this information is not current. Without a contact, no further information on whether the dam is actively managed could be obtained. According to Massachusetts Office of Dam Safety the surface area of the impoundment is 9 acres. Shown in Figure B-5 is a picture of the dam.

3.7 Cook Bridge Dam and Old Mill Pond Dam

Similar to Potter Road Dam, the Cook Bridge Dam and Old Mill Pond Dam (both located in Douglas), which are separated by a short distance, also appear to be abandoned based on numerous inquiries to determine the ownership. The Massachusetts Office of Dam Safety indicated that Guilford Industries (now IFGF) owns the Old Mill Pond Dam; however, this information is not current. Neither impoundment is sizeable (based on visual observation), thus it is assumed that the facilities do not have the ability to significantly regulate flow. Shown in Figure B-6 and Figure B-7 are pictures of the Cook Bridge Dam and Old Mill Pond Dam, respectively.

3.8 Gilboa Pond Dam

Gilboa Pond Dam is owned and operated by IFGF in Douglas. The dam has a normal storage capacity of approximately 150 acre-feet, surface area of 21 acres and dam height of 14 feet (Source: National Inventory of Dams). The dam has approximately six inch flashboards that remain in place year round. The water elevation is maintained at the top of the flashboards to convey water to the mill.

A sluice gate, capable of draining the impoundment, is used only during flood periods to reduce the amount of water flowing over the spillway. The dam is essentially operated as run-of-river year round, except for water withdrawals used for processing which is withdrawn from the inflow (more information is provided later on water withdrawals). A continuous minimum flow of 16 cfs is maintained below the dam; this flow is augmented by releases from Manchaug and Whitin Reservoirs in the summer, in conjunction with inflow from the incremental drainage area. Gilboa Pond is not drawn down to maintain 16 cfs.

Shown in Figure B-8 are pictures of the dam and the staff gage- the gage is located below the dam and is used to confirm the minimum flow of 16 cfs. IFGF records the instantaneous river stage and converts it to flow. It is interesting to note that the drainage area at Gilboa Pond is approximately 31 mi^2, thus a minimum flow of 16 cfs is equivalent to a flow per square mile of 0.52 cfsm.

As discussed later, IFGF has a water withdrawal from Gilboa Pond that is subject to the Massachusetts Water Management Act. In addition, IFGF has a National Pollutant Discharge Elimination System (NPDES) permit to discharge treated effluent to the Mumford River, just below Gilboa Pond Dam.

3.9 Lackey Pond Dam

Lackey Pond Dam was renovated in 1999 through a partnership between Ducks Unlimited, MassWildlife, Ocean State Power, Uxbridge Foundation, Rocky Bridges Memorial Fund, David and Christine Driven, James and Marsha Greet, Darnel Mitchell and Concerned Citizens for Lackey Pond.   The renovation included the restoration of 150 acres of prime wetlands habitat for resident and migratory waterfowl and waterbirds. The dam provides consistent water levels for warm water fish, reptiles, amphibians, aquatic plants and the entire wetlands and wildlife community.

The following was provided on the MassWildlife website in September 2000: "Restoring the dam, upstream impoundment and surrounding wetlands represents another step toward improving the health of the Mumford River and the Blackstone Watershed. Exploited during the industrial revolution by machine works, woolen mills and untreated sewage, these rivers were among New England's most polluted waterways. Today, the rivers and their legacy of mill ponds are recovering and have become popular destinations for canoeists, bass fishermen, waterfowlers and birders."

According to the National Inventory of Dams, Lackey Pond Dam is approximately 6 feet high and 130 feet long. It is equipped with one sluice gate and a fixed spillway crest. The Lackey Pond Dam and water levels are managed by MassWildlife. Information on the operation of the dam was provided by Mr. H. Heussman of MassWildlife. According to Mr. Heussman the State is still experimenting with managing water levels to achieve the best use for waterfowl and aquatic resources. In the last three years, water levels were lowered in the spring via the sluice gate while in the summer, water levels were raised approximately six inches. There is no minimum flow requirement below the dam; however, Mr. Heussman indicated that flow is continually maintained below the dam- i.e., there is never a period when water levels are below the spillway crest and the sluice gate is closed. The facility does not include any flashboards.

The discharge from Lackey Pond Dam travels a very short distance (short riverine reach) under the Lackey Dam Road, before becoming impounded at Meadow Pond. Shown in Figure B-9 are pictures of Lackey Dam.

3.10 Reservoirs Nos. 6, 5 & 4 (Tributary to Whitins Pond)

Whitinsville Water Company (WWC) owns and operates three dams in a series on Cook Allen Brook, a tributary to Whitins Pond. From upstream to downstream order they include Reservoir No. 6, No. 5 and No. 4 (Figure 3.0-1). These reservoirs are operated for water supply purposes. Water withdrawals do not occur directly from the reservoirs; rather a groundwater withdrawal is located directly below Reservoir No.4- referred to as the Cook Allen Brook Tubular Wellfield.

Basic information on all three dams and impoundments are summarized in Table 3.10-1.

Table 3.10-1: Reservoir Nos. 6, 5, and 4- Dam Height, Surface Area, Normal Storage

Reservoir No.	Storage Height (feet)	Surface Area (acres)	Normal Storage (acre-feet)
6	14 feet	15 acres	55 acre-feet
5	36 feet	25 acres	220 acre-feet
4	24 feet	10 acres	69 acre-feet

Source: National Inventory of Dams

WWC sporadically measures the water elevation of all three reservoirs at various times of the year. Measure downs are taken to the water surface from a set height or reference mark. Shown in Figures 3.10-1, 3.10-2, and 3.10-3 are the water elevations for Reservoir No. 6, No.5, and No, 4, respectively, for calendar year 2002. As the figures show, the reservoirs are seasonally operated by lowering water levels in the summer when natural flows start to subside; in 2002 this occurred around the beginning of July. The maximum drawdown for Reservoir No. 6, No.5, and No.4, based on the available sporadic measurements were 10 feet, 16 feet, and 10.25 feet, respectively. WWC also provided stage versus storage curves for Reservoir No. 6 and 5 as shown in Figure 3.10-4 and 3.10-5, respectively (no data was available for Reservoir No. 4).

There are no minimum flow requirements below any of the dams and in many instances gates are closed resulting in only leakage below the dams. It should be noted that all three reservoirs are remotely located in a forested area; there is no development around these impoundments. As described later in the recommendations section, it is suggested that minimum flows be maintained below all three dams.

3.11 Carpenter Reservoir

Carpenter Reservoir (83 acres) is located on an unnamed tributary to Whitins Reservoir, which enters the pond from the north. According to WWC, owners and operators of the project, Carpenter Reservoir is not regulated throughout the year. The dam is operated as run-of-river where inflow equals outflow on an instantaneous basis.

3.12 Whitins Pond and Dam

Whitins Pond in Northbridge represents the outlet of a major tributary (drainage area = 12.6 mi^2) to the Mumford River. Whitins Pond drains almost directly into Meadow Pond (there is a very short riverine reach), which is part of the Mumford River mainstem[18]. Shown in Figure B-11 are

[18] The drainage area at the Whitins Pond Dam and Meadow Pond Dam are 12.6 mi^2 and 48.3 mi^2, respectively.

pictures of the dam, which includes a gate (under a manhole cover). WWC owns and operates the dam. WWC indicated that there is no flow regulation at the facility- the dam is effectively operated as a run-of-river project. There is a short distance between the Whitins Pond and Meadow Pond (the pictures illustrate this) and there is very little head differential between the impoundments (meaning that the water surface elevations of the two water bodies is virtually the same). WWC operators also indicated that during dry periods no water passes over Whitins dam due to impoundment evaporation; however, it is likely that WWC water withdrawals in this subbasin also contribute to low flow conditions (a portion of WWC water withdrawals are removed from the Mumford River Basin). There could also be instances where Whitins and Meadow Ponds are essentially one impoundment, if water levels at Meadow Pond rise enough to inundate Whitins Dam.

3.13 Meadow Pond Dams ("The Shop Dam" and "Douglas Bridge Dam")

There are two dams located within the Meadow Pond impoundment. The upper dam is owned by The Shop. It is a former mill pond that has been inactive for many years. According to Paul Goguen of WRT Management, the mill pond is operated in as a run-of-river manner where inflow equals outflow. Water elevations rise and fall according to the spillway rating curve. When inflow exceeds the discharge capacity water levels rise, but eventually subside when inflows decrease. There is a sluice gate at the dam; however, it has remained in a closed position for at least 10 years, probably longer. In fact, the screw to open the gate has rotted. Shown in Figure B-11 are pictures of the dam.

Just downstream of The Shop Dam is another unnamed dam- for purposes of this report it has been referred to as the Douglas Street Dam. The dam is located just behind the Northbridge town offices. Inquires with the Northbridge town assessors were made to determine ownership of the dam- no owner could be identified. As with most of the abandoned dams, it is assumed that the facility does not regulate flow, rather inflows equal outflows on an instantaneous basis. Shown in Figure B-12 are pictures of the dam taken from the Douglas Street Bridge. Also shown with the series of Figure B-12 pictures is a plan map showing the locations of the Shop and Douglas Bridge Dams, which was obtained for the Northbridge town office.

3.14 Linwood Dam

The Linwood Pond and Dam is owned and operated by Mumford Mills, LLC. Information on the facility was provided by Mr. Tom Wickstrom, attorney for Mumford Mills, LLC. According to the National Inventory of Dams, the dam is approximately 17.5 feet high, and the impoundment has a normal storage capacity of 300 acre-feet and surface area of 47 acres.

According to Mr. Wickstrom there is no manipulation of inflow to the project- essentially the project is operated as a run-of-river manner year round. There is a gate to lower the reservoir elevation; however, it has not been opened in approximately 20 years. No flashboards are used at the site. Shown in Figure B-13 are pictures of the facility.

3.15 Whitin Pond and Dam

Similar to many of the dams in the Mumford River Basin, no owner could be identified for the Whitin Pond Dam. Shown in Figure B-14 is a picture of the Whitin Reservoir spillway and gate. The gate diverts water to a forebay, toward a former mill area, and then returns the flow to the Mumford River downstream of the Crown and Eagle Building (Hartford Avenue, Uxbridge). Thus, a portion of the Mumford River mainstem is bypassed by the project. The magnitude of the diversion is unknown.

3.16 Caprons Pond and Dam

Again, no owner could be identified for the Caprons Pond Dam. The dam includes a canal with sluice gates along the eastern shore, and a sluice gate on the western shore. The eastern sluice gates are opened to provide water to a stream that was built through Capron Park. However, the sluice gates are at a higher elevation than the dam, thus the gates are only opened at high flows. The western sluice gate appears to be fixed in an open position (Personal Communication, Therese Beaudoin, 2003). Figure B-15 contains pictures of the facility.

3.17 Summary of Dam Operations

The main goal of this study is to determine the cause(s) of low flows in the Mumford River, particularly during the summer period. There are a host of variables that can contribute to low flow conditions, including water withdrawals, low precipitation, land use changes and dam operations.

In this section, dam operations were evaluated to determine if flows were regulated to cause artificially low or high flow conditions. Flow regulation can occur due to hydropower operations, manufacturing water withdrawals, weed control, recreation, or water supply needs. As stated above, there is currently no hydropower generation on the Mumford River[19], thus flows are not pulsed or peaked at various hours of the day. Although historically there were numerous water withdrawals from dams for manufacturing purposes, this has dwindled to only one – the Interface Fabrics Group Finishing, Inc. (Guilford of Maine) withdrawal at Gilboa Pond in Douglas.

An evaluation of the Mumford River mainstem dams is difficult to conduct as many of the dams are abandoned and ownership could not be determined. Many dams are now well over 100 years old and were last used during the manufacturing boom at the turn of the century. Virtually all of the mills are no longer operational and the dams, which were instrumental at the time, are now abandoned and serve no purpose. It was assumed that these dams, by default, are run-of-river facilities without any artificial regulation of flow as no active management occurs. Thus, under this assumption these abandoned dams are not contributing to low flow conditions.

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[19] Although there is no hydropower on the Mumford River currently, a recent article in the Worcester-Telegram & Gazette indicated that "Alternatives", a non-profit organization was awarded grant money to upgrade a dormant hydropower facility near Stone Mill Pond, the waterbody impounded at the Douglas Road Bridge behind the Northbridge Town Hall.

Several dams were identified as actively managed during the spring and fall when flashboards are installed and removed, respectively. Flashboards are installed near the end of the spring freshet to maintain a full pond; while in the fall the flashboards are removed to lower the impoundment. The use of flashboards artificially regulates the flow during periods in the spring and fall. Installing flashboards in the spring limits flow to leakage through the dam while the impoundment fills (unless the facility has a low level gate). In the fall, flashboard removal could create artificially high flows downstream. During the summer, when flows are traditionally the lowest, owners that could be contacted indicated that the facilities are not regulated, rather inflow equals outflow on a continuous basis. Thus, operation of these dams are not likely to be contributing to low flow conditions in the summer as the flashboards remain in-place and the projects are operated as run of river.

Based on Gomez and Sullivan's research, the only projects where flow is regulated on a daily or seasonal basis throughout the year (including the summer) include: Manchaug and Whitin Reservoirs and Reservoir Nos. 6, 5, and 4. These five reservoirs are seasonally operated by regulating discharges. As noted above, Manchaug and Whitin Reservoirs are operated to ensure a continuous flow of 16 cfs below Gilboa Dam. In fact, in the last few years, both reservoirs have been lowered in the summer to augment low flows. Consequently, these two reservoirs are regulated to artificially increase flow in the Mumford River during the summer low flow season. However, Reservoir Nos. 6, 5, and 4 are operated to maximize the water withdrawn by WWC at Reservoir No. 4. These three reservoirs are located on Cook Allen Brook, a tributary to Whitins Pond in Sutton. During the summer period, when water demands typically peak, water usage increases and thus withdrawals from this watershed increase, resulting in less streamflow to the Mumford River (and as noted later, a portion of WWC's water withdrawals are removed from the Mumford River Basin).

In summary, it does not appear that dam operations are causing low flow conditions (with the exception of Reservoir Nos. 6, 5 and 4) in the Mumford River during the summer. In fact, Manchaug and Whitin Reservoirs are supplementing naturally low flow conditions by reducing water levels in the summer to maintain 16 cfs below Gilboa Pond (although as described later the IFGF gage accuracy is questionable and relocation/recalibration of the staff gage is recommended to confirm the magnitude of flow).

There a few other noteworthy items to consider. First, although all of the dams in the Mumford River Basin fall under state jurisdiction, there are no regulations that govern operations (such as flashboard operation) although the owner must report to the Massachusetts Office of Dam Safety. There are no required minimum flows below any of the projects, with the exception of maintaining 16 cfs in Douglas. Second, although the majority of dams are not contributing to low flow conditions in the summer, the impoundments themselves are subject to evaporative losses. As noted earlier there is approximately one dam for every mile of the Mumford River- a large number per mile. In addition, based on the National Inventory of Dams database, the total surface area of all impoundments in the basin is approximately 1,574 acres (2.5 sq mi) or roughly 4.4% of the total drainage basin. The amount of evaporation losses from these impoundments is discussed next.

The Northeast Climate Data Center in Ithaca, NY was contacted to obtain evaporation data in the project area to estimate the volume of water lost to evaporation. It should be noted that this analysis provides only a ballpark approximation of the volume of water lost to evaporation as there are many factors affecting lake evaporation (including overhead cover, size of impoundments, fetch, etc). The closest climatological station is located at the Worcester airport. It should be noted that evaporation rates, provided by the Northeast Climate Center, were indirectly computed using the Penman equation, rather than relying on more standard pan[20] evaporation rates. The Penman equation indirectly estimates lake evaporation by obtaining data on other climatological variables such as wind speed, air temperature, vapor pressure, and solar radiation. Shown in Table 3.17-1 are the evaporation rates in inches on a monthly basis for the months May-September and the estimated loss of water due to evaporation on a MG, MGD and cfs basis. Also shown on Table 3.17-1 is the average monthly precipitation rate for the Whitinsville precipitation gage for the period 1931-2002. As the table shows, evaporation outpaces precipitation for May-September, resulting in a net loss of water.

Table 3.17-1: Estimated Water Lost from Impoundment Evaporation in the Mumford River Basin

Month	May	Jun	Jul	Aug	Sep	Total
Evaporation Rate (inches/month)	5.40	5.62	5.91	5.28	3.89	26.1
Average Precipitation Rate (inches/month)	3.50	3.64	3.58	3.95	3.75	18.4
Total Reservoir Surface Area (acres)	1,574	1,574	1,574	1,574	1,574	
Volume of Water Lost to Evaporation (MG)	231 MG	240 MG	253 MG	226 MG	166 MG	1,115 MG
Volume of Water Lost to Evaporation (MGD)	7.4 MGD	8.0 MGD	8.1 MGD	7.3 MGD	5.5 MGD	
Volume of Water Lost to Evaporation (cfs)	11.5 cfs	12.4 cfs	12.6 cfs	11.3 cfs	8.6 cfs	

Although the volume of water lost to evaporation is only an approximation, the order of magnitude is relatively high when compared to the drainage area size. For example, losing 253 MG or 12.6 cfs of water during July, relative to the Mumford River drainage area of 56.6 mi^2, represents a flow per square mile (cfsm) of 0.22 cfsm. This is considered to be a high level of evaporative losses given that the USFWS recommends summer minimum flows equivalent to 0.5 cfsm absent any detailed studies.

To summarize, operation of most dams do not appear to be causing artificially low flows in the summer. The two most regulated reservoirs, Manchaug and Whitin, are actually enhancing low flows in the summer by utilizing storage, but reducing flows in the spring to refill the reservoirs. The loss of water from the basin due to impoundment evaporation was grossly estimated, resulting in a large loss of water from base flow. Readers should also keep in mind that observations of low flow conditions have been more prominent in 1999-2002, relative to previous years. Because the dams have been present for many years, the evaporation rates are likely to be fairly constant over time, including the 1999-2002 period.

[20] The National Weather Service measures evaporation using a standard evaporation pan called a Class A pan.

4.0 Mumford River Basin- Summary of Water Management Act Withdrawals

The Massachusetts Water Management Act (WMA) became effective in March 1986. The purpose of the Act is to ensure adequate volume and quantity of water for all citizens of the Commonwealth, as well as to protect the natural environment of the water in the Commonwealth. Implementation of the Water Management Act has taken place in two phases: registration and permitting of water withdrawals.

The deadline for filing registration statements was January 4, 1988. The purpose of the registration was to accommodate continued water use for existing water withdrawals and to provide the Massachusetts Department of Environmental Protection (MDEP) with information needed to begin the process of comprehensive water management. Registrations were based on the applicant's average water use for the period 1981-85. The permitting phase of the program went into effect over several years. The deadline for submitting permit applications for the first round of permitting in the Mumford River Basin was in February 28, 1993.

Anyone with an unregistered water withdrawal in Massachusetts that averages over 100,000 gallons per day (GPD) is required to obtain a permit under the WMA. Persons who have registered and now exceed their registered withdrawal by 100,000 GPD or propose an increase in the amount they withdraw are also required to obtain a permit. These conditions apply to any entity withdrawing water such as public water suppliers and industrial, commercial, golf courses and agricultural users. Those who obtain (purchase or transfer) their water from another water system that already has a permit or registration do not require a permit.

There are several water withdrawal locations within the Mumford River Basin, with the majority of users withdrawing less than 100,000 GPD. Figure 4.0-1 is a map depicting the location of all water supply water withdrawals (this does not include all industrial users, as Mass GIS does not have this information readily available). Withdrawals exceeding 100,000 GPD, which are subject to the WMA are shown on Figure 4.0-2 and are listed in Table 4.0-1– this list includes industrial users.

Table 4.0-1: Registered and Permitted Water Withdrawals in the Mumford River Basin (>100,000 GPD or 0.1 MGD)

Name	Permit/ Registration No.	Registered No. of Withdrawal Points (SW- surface water, GW- groundwater	2001 Average Daily Rate (MGD)	Allowed Average Daily Withdrawal in 2001 (MGD)
Public Water Suppliers				
Whitinsville Water Company, Inc.	9P-2-12-216.01 (Permit No.) 2216000 (Registr. No.)	1 SW 3 GW	1.33	1.34
Douglas Water Department	9P-2-12-077.01 (Permit No.) 2077000 (Registr. No.)	4 GW	0.30	0.34
Industrial Users				
Interface Fabrics Finishing, Inc.	9P321207702 (Permit No.)	1 SW	0.20	1.50
Whitinsville Golf Club	2-12-216.03 (Registr. No.)	1 SW	0.08 over 180 days	0.047 over 180 days

Gomez and Sullivan visited the MDEP Springfield and Worcester offices to obtain copies of the reports listed below, which were needed to evaluate water withdrawals in the Mumford River Basin:

- The Registration Statement for each water withdrawal,
- The water withdrawal permit [Massachusetts General Law (MGL) c 21G],
- Public Water Supply Annual Statistical Reports (PWSASR) from each water supplier for the period 1998 to 2001, and
- Registered & Permitted Withdrawals Annual Reports for IFGF and the Whitinsville Golf Club for the period 1998 to 2001. It should be noted that the public water supply reports and industrial reports contain the same basic information, although the public water supply reports contain information on peak water usage.

Each of the four WMA users in the Mumford River Basin were examined in this report. All water users were called to gain a better understanding of their system. The annual reports provide limited information, and telephone calls helped refine the evaluation. In addition, to ensure that the description of each water user was accurate, the sections below were sent to each supplier for review and comment.

Each WMA user was evaluated to understand the magnitude and timing of water withdrawals, as well as the timing of peak withdrawals (applies only to public water suppliers). In addition, other components of each water user's system were evaluated including: population served, average daily consumption (gallons per capita per day, gpcd), peak daily consumption, main water users (residential, commercial, etc), unaccounted for water and any information on water conservation plans.

Another key component of our research was to determine if the water supplier had storage capacity within their system such as reservoirs or sizeable storage tanks. The purpose for collecting this information was to determine if storage capacity could be used to supplement demand during low flow periods such as in the summer, when aquatic resources are most apt to be affected by reductions in the magnitude of natural flow. Summer water withdrawals could presumably be curtailed if sufficient storage capacity were available to supplement water supply needs, which would result in less stress on aquatic resources.

A few notes are worth mentioning before reviewing the average daily consumption [in gallons per capita day (gpcd)] and unaccounted for water (UAW) findings below. It is important to note that in some of the smaller towns the population served is overestimated, which results in a low residential consumptive use in gpcd. Some residents in a town also utilize private wells, instead of relying on public water. Also, the water suppliers know the number of residential service connections, but not necessarily the number of people per household. The MDEP uses a residential consumption rate 70-80 gpcd to flag excessive water use. When reviewing the Public Water Supply Annual Statistical Reports, the MDEP determines if the reported gpcd is excessively high (greater than 70-80 gpcd), and then probes further into the cause(s) through leak detection, inaccurate population estimates, summer water use and other water conservation issues. Some water suppliers report an inflated population, which results in an unrealistically low estimate of gpcd. For example, the Whitinsville Water Company reported a residential consumption rate of 28 gpcd. A value this low is unrealistic and is most likely a function of the population reported.

Similarly, if unaccounted-for-water (UAW) exceeds 10-15%, it is a flag to the MDEP to investigate further the breakdown of lost water. Often water providers do not differentiate water lost to hydrant flushing or fire fighting, which, according to MDEP is not technically UAW. Systems that are below 10-15% are still required to conduct leak detection surveys and pursue water conservation strategies.

Shown in Appendix C are scanned copies of Registration Statements, Public Water Supply Annual Statistical Reports (PWSASR), and Registered & Permitted Withdrawals Annual Reports. The data is organized as follows: Whitinsville Water Company, Douglas Water Department, Interface Fabrics Group Finishing and Whitinsville Golf Course.

4.1 Whitinsville Water Company, Inc.

Public Water Supply Identification No.:	2216000
Water Management Act Permit No.:	9P21221601
Water Management Act Registration No.:	21221604

The Whitinsville Water Company (WWC) has four registered withdrawal points as summarized in Table 4.1-1.

Table 4.1-1: Whitinsville Water Company: Withdrawal Locations and Activity Status

Source	Source Code	Location	Groundwater (GW) or Surface Water (SW)	Status as of 2003
Meadow Pond Tubular Wellfield	216-01G	Carr Street, Northbridge	GW	Active
Sutton Wells (Cook Allen Brook Tubular Wellfield)	216-02G	Mendon Road, Sutton	GW	Active
Gravel Packed Wellfield	216-03G	Meadow Pond, Whitinsville	GW	Emergency
Meadow Pond	None provided	Meadow Pond, Whitinsville	SW	Inactive, allowed by permit

Over the period 1998-2001 withdrawals have predominantly occurred at the Meadow Pond Tubular Wellfield and the Cook Allen Brook Tubular Wellfield. In addition to these withdrawals, water is trucked from Meadow Pond for use as cooling water at the Milford, MA power plant (located outside of the Mumford River Basin). In 1999 (Jun, Jul and Aug) and 2001 (Aug, Sep, Nov and Dec) 21.4 MG and 16.1 MG were trucked from Meadow Pond, respectively (no water was trucked in 1998 and 2000).

In April 2002, WWC requested permission from the MDEP to reactivate the Gravel Packed Wellfield. Mr. Jim Ouellet, Manager of WWC, indicated that the Gravel Packed Wellfield is currently not operating because of iron and manganese issues, but could be activated if needed.

WWC serves water to its service area of Whitinsville within Northbridge and also sells water to the Northbridge Water Department, which does not have its own water supply source. Over the last four years (1998-2001), average annual sales accounted for 218 MGY, or 0.60 MGD.

Although the main water sources are the Meadow Pond Tubular Wellfield and the Cook Allen Brook Tubular Wellfield, WWC manages several reservoirs in the basin to replenish groundwater levels. For example, WWC owns and operates three small reservoirs (Reservoir Nos. 6, 5 and 4) on Cook Allen Brook as shown in Figure 4.0-2. Just below the most downstream dam, Reservoir No. 4, WWC withdraws water at the Cook Allen Brook Tubular Wellfield. WWC also operates Carpenter Reservoir and Whitins Pond.

It should be noted that Zone II wellhead protection areas are shown in Figure 4.0-2, which was obtained from Mass-GIS. Therese Beaudoin of MDEP indicated that there is also a Zone II wellhead protection area near the outlet of Whitins Pond (although this was not included in the Mass GIS coverage).

Shown in Table 4.1-2 are the authorized total withdraws (from all four sources) in five year increments.

Table 4.1-2: Whitinsville Water Company, Allowable Withdrawal Volumes

Period	Daily Rate (MGD)	Total Annual (MGY)
03/01/1994-02/28/1999	1.26	459.9
03/01/1999-02/28/2004	1.34	489.1
03/01/2004-02/28/2009	1.43	521.95

4.1.1 Annual and Monthly Withdrawal Volumes

Figure 4.1.1-1 depicts the WWC annual total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1998-2001 as reported on the PWSASR. As noted above, in 1999 and 2001 water was withdrawn from Meadow Pond to provide cooling water for the Milford, MA Power plant. These withdrawal volumes were not reported on the PWSASR's. Because the water was not used for public water supply WWC filed a similar but separate form[21] with MDEP for industrial, agricultural and golf course withdrawals. It should be noted that the peak withdrawal rates shown in Figure 4.1.1-1 do not include the cooling water withdrawal- the peak withdrawal is related directly to water supply.

WWC's total annual withdrawal volume has generally increased from 402 MG in 1998 to 503 MG in 2001 (this year included water pumped from Meadow Pond and trucked to the Milford, MA Power plant), a 25% increase in four years. The 1999 and 2001 annual withdrawals exceed the allowable withdrawal of 489 MG, however, technically WWC remains in compliance. Water suppliers are allowed an additional 100,000 GPD (or 36.5 MG/year) before a permit modification would be required in accordance with the WMA. Thus, the withdrawal can increase to 525.6 MG/year and remain in compliance. It should be noted that our analysis focused on the period 1998-2001. Mr. Jim Ouellet of WWC provided historical annual water usage for the period 1996-2002 as follows (these numbers do not reflect withdrawals for the Milford, MA Power plant):

1996	1997	1998	1999	2000	2001	2002
422 MG	389 MG	402 MG	475 MG	467 MG	484 MG	461 MG

Although water usage increased by 25% between 1998 and 2001 (which includes trucked water), over the period 1996 to 2002, water usage increased by 9%.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.1.1-2 is a bar graph depicting, by month, the average water withdrawals from the Cook Allen Brook Tubular Wellfield, Meadow Pond Tubular Wellfield, and Meadow Pond from 1998-2001 (the monthly totals include cooling water withdrawals). As anticipated, water demands are highest in the summer (July- 53.0 MG/month) due to lawn irrigation, car washing and filling of swimming pools. During summers of low precipitation, water demands (and hence withdrawals) are typically greater to meet rising water demands, particularly for lawn irrigation. The lowest demand occurs in the winter (February-31.3 MG/month).

During the four years examined, the peak demand occurred during the summer months as follows: June (2 times), July (once), and August (once). The average difference between average daily demand and peak demand (which does not include withdrawals from Meadow Pond for the Milford, MA Power plant) over the past four years is approximately 0.95 MGD. During this four-year period the ratio of peak demand to average daily demand was 1.74. A high ratio such as 1.74 reflects a greater difference between peak and average demand.

[21] This form is referred to as the "Registered & Permitted Withdrawals Annual Report".

4.1.2 Storage Capacity

WWC maintains three finished water storage tanks with a capacity of 3.85 MG. As noted above, WWC has a reservoir storage network consisting of three reservoirs on Cook Allen Brook, a tributary to Whitins Pond. In upstream to downstream order the reservoirs are Reservoir No. 6, Reservoir No. 5 and Reservoir No. 4 with normal storage capacities of 55, 69 and 220 acre-feet, respectively. Reservoir water levels are adjusted seasonally to maximize the availability of water to the Cook Allen Brook wellfield below Reservoir No. 4. In addition to these reservoirs, WWC also operates and controls discharges from Carpenter Reservoir and Whitins Pond.

4.1.3 Customers/Unaccounted Water

From 1998 to 2001 an average of 48% (218 MG) of the water supply was sold annually to the Northbridge Water Department, while the remaining 52% (238 MG) was used by Whitinsville Water Company. Of this 238 MG, approximately 35% (83.3 MG annually) is delivered to the residential community, with the balance being delivered to industrial, commercial and other users. Over the four-year period unaccounted for water (UAW) averaged 9.5% of their water withdrawals. This value is below the state's water conservation goal of less than 10%. WWC indicated that much of the UAW was a result of flushing 25,000 GPD at the Whitin well field due to iron.

For Northbridge's water system, approximately 64% of the water supply is delivered to the residential community with the balance being distributed among schools, industrial/agricultural, commercial, wholesalers, and other users. Over the four year period UAW averaged 12%, which is slightly above the state's water conservation goal of 10%. It should be noted that UAW in 2002 was 5.4%, thus efforts were made to reduce UAW.

4.1.4 Population Served

WWC reports that it served the same population during the summer and winter period, as the population remained nearly constant ranging from 14,000 in 1998 to 14,100 in 2001. The method of estimating the population served, however, has varied based on the PWSASR's. On the 2000 and 2001 PWSASR's, water suppliers were asked to indicate how the population served was estimated. In 2000, the population served (14,000) was based on census information, whereas in 2001 the population served (14,100) was based on the number of service connections.

Using the residential population served and dividing it by the number of gallons they consume per day (over a year) will yield the gallons per capita day (gpcd). The state's water conservation goal is to limit residential use to 70-80 gpcd. From 1998-2001, the reported residential water use has ranged from 28 gpcd to 32 gpcd, which is well below the conservation goal of 70-80 gpcd as shown in Figure 4.1.4-1. Although MDEP considers water use greater than roughly 70 gpcd as a flag, water use ranging from 28-32 gpcd is also a flag indicating some inaccuracies in the reporting (such as the population served). It is recommended that more accurate measures are implemented to estimate the population such that MDEP can better evaluate residential water use.

The average gallons per capita day was estimated for the Northbridge system as well. On the PWSASR's for Northbridge, they report the number of service connections, but not the entire population served. It was assumed that on average there were three people for each service connection. For example, in 1998 there were 1839 connections, for an estimated population of 5,517 people. The average gallons per capita day for the period 1998-2001 (see Figure 4.1.4-2) is approximately 69 gpcd, which is just below the 70-80 gpcd threshold.

4.1.5 Water Conservation Measures

According to WWC, informational pamphlets outlining water saving tips are mailed to customers. Ordinances are in place to implement mandatory outside water restrictions in times of severe drought. Because water demands are progressively increasing, it is recommended that more aggressive water conservation measures be implemented.

4.1.6 Return Flow

We visited the WWC to obtain information on the geographic extent of their water distribution system. Shown in Figure 4.1.6-1 is a map depicting the WWC's water distribution system, which shows a portion of the system being located outside of the Mumford River Basin. As noted above, WWC also sells water to the Northbridge Water Department, which has no water source (Whitinsville is a village on the southwestern side of Northbridge).

Mr. Ouellet indicated that approximately 60% of WWC's service territory is connected to a sewer system, with the remaining 40% on septic disposal systems (it is unknown what percentage of the 40% consists of septic systems located outside the Mumford River Basin). The sewer system eventually drains into the Northbridge Wastewater Treatment Plant, which is located on the Blackstone River. During precipitation events there is inflow into the sewer system, which is also transferred out of the Mumford basin. Likewise, infiltration to the sewer system occurs during periods of high water table. The magnitude of infiltration and inflow (I/I) is unknown. A very simplistic water budget was conducted to approximate the volume of water transferred out of basin and the volume of water lost to evaporation within the Mumford Basin. To conduct this analysis, the following assumptions were made:

- 60% of the WWC's service territory (including water sold to Northbridge) water is transferred out of the basin year round,
- the analysis did not account for I/I, thus the volume of water transferred out of basin is underestimated,
- for the 40% of water users with septic systems, it was assumed that 50% of the outdoor water use is lost to evaporation and evapotranspiration during the months May-September[22]. To estimate outdoor water use, winter water use was calculated by averaging monthly water withdrawals for the period October-April. This value was used

[22] MDEP estimates that approximately 50% of the outdoor water supplied in May through September is lost to evaporation and evapotranspiration due to lawn irrigation, filling of swimming pools, etc. The 50% estimate is used throughout this report.

as a typical “baseline” demand. Monthly water withdrawals during May-September that were in excess of the winter water use were considered to be outdoor use.

Given these assumptions, shown in Figure 4.1.6-2 is a bar graph depicting the volume of water retained in the Mumford Basin (via septic systems), the volume transferred out of basin, and the volume lost to evaporation on a monthly basis. It is recognized that these are gross assumptions; however, it is based on the best available data and provides an order of magnitude. In summary, a considerable volume of water is lost to evaporation or is transferred out of basin. Shown in Table 4.1.6-1 is the volume of water lost from the Mumford River Basin (including water sold to Northbridge) in MG per month. The volume sent out of basin is likely underestimated due to I/I and losses associated with customers that utilize septic systems outside the Mumford River Basin.

Table 4.1.6-1: Whitinsville Water Company (including water sold to Northbridge)- Approximate Volume of Water Lost from the Mumford River Basin- Averages based on the Period 1998-2001. All values in MG.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
20.1	18.8	20.5	21.7	28.8	29.8	31.2	27.4	24.2	21.5	19.5	20.5	284.0

It should be noted that the Northbridge Wastewater Treatment Plant (WWTP) was contacted to determine if they could isolate the volume of water treated from the Mumford River Basin. Unfortunately, it is very difficult to pinpoint the true volume of water being exported from the Mumford River Basin and treated at the Northbridge WWTP.

4.2 Douglas Water Department

Public Water Supply Identification No.: 2077000
Water Management Act Permit No.: 9P21207701
Water Management Act Registration No.: 21207701

The Douglas Water Department (DWD) has four registered withdrawal points as summarized in Table 4.2-1 and shown in Figure 4.0-2 (Glen Street Wells #1 and #2 are shown as one point on Figure 4.0-2). Their withdrawals are concentrated near the Riddle and Centerville Brook drainage areas, along the south-central portion of the basin, just upstream of the center of Douglas.

Table 4.2-1: Douglas Water Department: Withdrawal Locations and Maximum Allowable Volumes

Source	Source Code	Location	Groundwater (GW) or Surface Water (SW)	Status as of 2003	*Maximum Allowable Withdrawal
Vacuum Tubular Wells	077-01G	West Street	GW	Active	0.22 MGD
Gravel Packed Well (also known as Turbine Station)	077-02G	West Street	GW	Active	0.32 MGD
Glen Street, Well #1	077-03G	Glen Street	GW	Active	0.21 MGD
Glen Street, Well #2	077-04G	Glen Street	GW	Active	0.24 MGD
* Withdrawals from individual water sources are not to exceed the approved daily volumes listed.					

Prior to 2001, the DWD was registered for two groundwater withdrawals, the Tubular Wellfield and Turbine Station. In 1994 two additional sites, Glenn Street Wells 1 and 2, were approved for use as a public water supply source however, they were not added to the WMA Permit at that time. In 2001, the combined authorized withdrawal was 0.314 MGD or (124.1 MGY) (Table 4.2-2).

Table 4.2-2: Douglas Water Department, Allowable Withdrawal Volumes

Period	Daily Rate (MGD)	Total Annual (MGY)
03/01/1994-02/28/1999	0.31	113.2
03/01/1999-02/28/2004	0.34	124.1
03/01/2004-02/28/2009	0.37	135.1

DWD does not sell to or purchase water from any outside vendors.

4.2.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.2.1-1 is the annual total withdrawal volume (MGY), average daily withdrawal (MGD), and peak withdrawal (MGD) for the period 1998-2001. Annual withdrawal volumes were similar throughout the period ranging from 95 MG in 1999 to 108 MG in 2001. All annual withdrawals were within the annual limit of 124.1 MG.

From 1998 to 2001, the peak demand generally occurred during the summer months as follows May (1), June (2), and July (1). Over the past four years, the average difference between the average daily demand and peak demand was approximately 0.24 MGD. During this same period the ratio of peak demand to average daily demand was 1.9. This is considered a relatively high ratio, indicating high summer usage.

The seasonal demand of water was also evaluated to determine if the timing and magnitude of water usage varied throughout the year. Shown in Figure 4.2.1-2 is a stacked bar graph depicting, by month, the average water withdrawals from the Tubular Wellfield, Turbine Station, and the Glenn Street Wells 1&2. Water demands were highest during the months of May, June and July (9.8 MG/month), and lowest during November (7.3 MG/month).

4.2.2 Storage Capacity

The DWD maintains two active water storage tanks, the Church Street storage tank installed in 1950 with a capacity of 0.25 MG and the Franklin Storage Tank installed in 1998 with a capacity of 0.75 MG. The tanks are used primarily to pressurize the system.

4.2.3 Customers/Unaccounted Water

According to DWD, during the period 1998 to 2001, residential and commercial customers were provided 77.0% and 2.8% of their water supply, respectively. During the same period the average unaccounted for water was 13.3%. This value exceeds the state's water conservation goal of less than 10% and further investigation is warranted as to causes of unaccounted for water. The DWD reported a number of leaks during 2000 and 2001. Leak detection surveys were completed in August 2001, and corrective actions were taken.

4.2.4 Population Served

Shown in Figure 4.2.4-1 is the population served by DWD, and the residential gpcd for the period 1998-2001. The DWD serves approximately 3,175 customers during the winter months, while the population increases slightly during the summer. Population levels remained relatively stable over the period examined. Estimates were determined by multiplying the number of connections (1,058) by three. Average daily usage for residential users was 67 gpcd, which is below the state's water conservation goal of 70-80 gpcd.

4.2.5 Water Conservation Measures

To decrease water consumption, conservation tips are mailed with customer bills, and ordinances are in place to enact mandatory outside water use restrictions. DWD also has a drought management plan that calls for various ways to reduce usage such as odd-even lawn watering. In December 2001, DWD also banned any future irrigation systems within their service territory. In addition, no wells can be drilled in the Zone 2 wellhead protection area. As stated earlier, DWD has had problems with leaks; as a result, they are required to perform bi-annual leak detection surveys, and maintain records of any repairs made.

4.2.6 Return Flow

Based on discussions with the DWD, their water distribution system covers approximately 30-35% of the town of Douglas (see Figure 4.2.6-1 illustrating the water distribution system- the distribution system was saved as a picture and laid over the base map, thus the quality is not optimal). We visited the DWD and obtained maps showing the water supply and town sewer systems. The water supply system encompasses a larger area of the town than the sewer system and therefore many customers that are serviced by public water utilize septic disposal systems.

Approximately 22%[23]of the water users are connected to the East Douglas WWTP sewer system (see Figure 4.2.6-2 illustrating the sewer system, which is a picture laid over the base map), where wastewater is collected, treated and then discharged to the Mumford River just upstream of Gilboa Pond. It should be noted that 56% of the town of Douglas is located in the Mumford River watershed, however, the entire water distribution system and wastewater collection system are located within the Mumford River watershed, thus there is no out of basin transfer.

As shown in Figure 4.0-2, all four groundwater withdrawals are located within the Centerville and Riddle Brook watersheds, which drain into the Mumford River (from the south) just upstream of downtown Douglas. Between the withdrawal locations and the East Douglas WWTP return flow, there is approximately 0.85 miles of the Mumford River that is bypassed. In addition, infiltration and inflow drains into the sewer system.

All operators with a NPDES permit must report their average monthly discharge of treated effluent to the MDEP and the Environmental Protection Agency (EPA). Monthly average discharges from the East Douglas WWTP were obtained for the period 1998-2001, the same

[23] There are approximately 3,175 water supply connections and 707 sewer tie-ins (707/3,175= 22%).

period in which water withdrawals were evaluated. Shown in Figure 4.2.6-3 is the following for the period 1998-2001: a) the monthly average water withdrawal, b) the monthly average volume of water lost to evaporation (assumed to be 50% of the outdoor water withdrawals from May-September), and c) the monthly average volume of water discharged at the East Douglas WWTP. As the plot shows, water withdrawals do not equal WWTP discharges due to the water distribution system covering a larger area of town than the sewer system as well as evaporative losses. Also, during the spring runoff months such as March and April, the water treated at the WWTP is considerably higher than other months, which is likely a function of infiltration and inflow to the sewer system.

Summarized in Table 4.2.6-1 is the estimated loss of water from the Mumford River Basin, which is based on 50% of the outdoor water use being lost to evaporation from May through September. Outdoor water use was estimated using the same approach as described above for WWC. Winter water use was calculated by averaging monthly water withdrawals for the period October-April. This value was used as a typical “baseline” demand. Monthly water withdrawals during May-September that were in excess of the winter water were considered to be outdoor use.

Table 4.2.6-1: Douglas Water Department: Approximate Volume of Water Lost from the Mumford River Basin, Based on Averages for the Period 1998-2001

May	Jun	Jul	Aug	Sep	Total
0.98 MG	0.95 MG	0.98 MG	0.55 MG	0.15 MG	3.62 MG

4.3 Interface Fabrics Group Finishing, Inc. (formerly Guilford of Maine Finishing Services, Inc.)

Water Management Act Permit 9P321207702

Interface Fabrics Group Finishing, Inc. (IFGF) owns and operates a textile finishing operation in East Douglas, Massachusetts. The operations supported at the facility include fabric washing, conditioning piece and package dying, topical treatment, inventory, steam generation, process cooling, and distribution. The facility withdraws water from Gilboa Pond[24] on the Mumford River and discharges treated effluent from IFGF’s wastewater treatment plant (to the Mumford River).

In 1991 IFGF was authorized to withdraw from Gilboa Pond an average daily volume of 1.18 MGD (or 430.7 MG annually). In 1999, allocations were increased to an average daily volume of 1.50 MGD (or 547.5 MG annually). (Table 4.3-1).

[24] Gilboa Pond is formed by a dam located on the Mumford River mainstem.

Table 4.3-1: Interface Fabrics Groups Finishing, Permitted Volumes

Period	Daily Rate (MGD)	Total Annual (MGY)
11/01/1991-02/28/1994	1.18	430.7
03/01/1994-02/28/1999	1.18	430.7
03/01/1999-02/28/2004	1.50	547.5
03/01/2004-02/28/2009	1.50	547.5

4.3.1 Annual and Monthly Withdrawal Volumes

Shown in Figure 4.3.1-1 is the annual total withdrawal volume (MGY) and average daily withdrawal (MGD) for the period 1998-2001. Since water withdrawals at IFGF are for industrial purposes, records of peak withdrawals are not required by MDEP. As Figure 4.3.1-1 depicts, the average annual water use has declined steadily from 99.4 MGY in 1998 to 72.7 MGY in 2001 (a 27% reduction). Throughout the entire period levels remained well below allocated annual withdrawals (Table 4.3-1).

To determine if water usage varied throughout the year the seasonal water use was evaluated as shown in Figure 4.3.1-2. Water withdrawals ranged from 5.7 MG in February to 8.2 MG in August. Generally, water usage at industrial plants remains consistent throughout the year.

4.3.2 Water Conservation Measures

IFGF has instituted significant water conservation and reuse measures resulting in less water consumption over time. IFGF recently submitted an updated comprehensive water use audit to the MDEP.

Water consumption decreased at the facility since it initiated operations in 1983. Several measures were implemented to reduce the volume of water used in the manufacturing process. During the late 1980’s, the facility installed a condensate return system in both the boiler feed operation and in the cooling operation. According to IFGF, water reuse increased by 80 percent and 30 percent, respectively. Additional water conservation measures were implemented, including the replacement of scouring and finishing equipment with a more water efficient substitute. During this time, facility personnel also performed frequent inspections of aboveground piping to search for leaks. In addition to repairing detected leaks, the facility replaced extensive sections of substandard piping throughout the facility during a rehabilitation of the building.

Several changes occurred with respect to the facility’s water usage during the period 1992-1994. During this time, equipment was installed for piece dyeing and backcoating operations, which increased water usage by approximately 212,000 GPD. Additionally, the facility installed a second washer line to meet production increases. The new equipment requires one-fifth of the water volume required by the first washer line. Yet, water usage increased by 16,000 GPD as a result of this operation.

IFGF reduced some of their required volume in 1992 by eliminating the wool stock-dyeing process from its operations. Water usage decreased by 100,000 GPD as a result of this process change. Even though the facility expanded many of their production processes during the early 1990's, the resulting increased demand for water remained well below the withdrawal limits set forth in the WMA Withdrawal Permit.

Implementing these advances in water reuse and conservation has yielded significant results. The amount of water withdrawn from Gilboa Pond/Mumford River from 1995 to 2002 has decreased by approximately 37%. Over the last three years, the amount of water recycled more than doubled from 3.7 to 7.8 MG.

4.3.3 Return Flow

IFGF has a National Pollutant Discharge Elimination System (NPDES) Permit to discharge treated wastewater. The treated wastewater includes process wastewater and portions of the facility's stormwater. Thus, measured discharges are not directly correlated to water withdrawals. In addition there are water losses attributable to evaporation during fabric drying operations.

Shown in Figure 4.3.3-1 is the withdrawal and discharge locations for IFGF. Figure 4.3.3-2 depicts the monthly water withdrawals (in MG/month) and treated effluent[25] (in MG/month) based on averages for the period 1998-2001. The purpose of this exercise is to see how much water is lost in the process from the point of withdrawal to the discharge location. As a general rule, wastewater discharges are greater than water withdrawals over the four year period. As IFGF indicated stormwater runoff is treated at the WWTP, which results in higher wastewater discharges during storm events. In addition, all of their sanitary water is sent to the East Douglas WWTP, and only industrial water is conveyed to IFGF's disposal system. The trend varies when evaluating individual years. For example, shown in Figure 4.3.3-3 are monthly withdrawal volumes and wastewater discharges volumes for calendar year 2001. During May, October, November and December 2001, water withdrawals exceed treated discharge by 2.49 MG, 2.39 MG, 2.04 MG and 2.92 MG, respectively, a total of 9.8 MG. Thus, there is a consumptive use of water.

Shown in Table 4.3.3-1 is a summary of the annual water usage and return flow for 1998-2001.

Table 4.3.3-1: Interface Fabrics Group Finishing: Annual Volume of Water Withdrawn and Returned (via treatment plant) to the Mumford River

Year	Annual Volume of Water Withdrawn from Mumford River	Annual Volume of Water Returned to the Mumford River	Withdrawal-Return Flow
1998	99.4 MG	128.7 MG	-29.3 MG
1999	85.7 MG	109.4 MG	-23.7 MG
2000	88.0 MG	96.4 MG	-8.4 MG
2001	72.7 MG	67.0 MG	+5.7 MG

[25] Treated effluent data (MG) was obtained from the Environmental Protection Agency (EPA) website (USEPA, 2003).

As the table shows, on an annual basis there is little difference between the withdrawal and return flows in 2000 and 2001, however, when investigating individual months (see 2001) there is a consumptive use. It is also interesting to note that wastewater discharges have decreased by 48 % between 1998 and 2001. This is a direct function of IFGF efforts to reduce water withdrawals.

As Figure 4.3.3-1 shows, the withdrawal and discharge points are relatively close together, thus the Mumford River mainstem is affected by the difference in water volume over a short distance.

4.4 Whitinsville Golf Club

Water Management Act Registration No.: 21221603

Whitinsville Golf Club (WGC), located on Fletcher Street in Whitinsville (Northbridge), withdrawals water from a single surface water site for golf course irrigation. WGC is registered to withdraw 8.54 MG during 180 days of operation (or 0.47 MGD). The WGC water use is currently below the 100,000 GPD threshold for mandatory water management registration; however they are eligible for voluntary registration. In 2002, WGC increased the surface area of the course and have expanded the irrigation system accordingly (Personal Communication, Therese Beaudoin, 2003). Thus, our analysis does not reflect the expected increased water usage resulting from expansion.

4.4.1 Annual and Monthly Withdrawal Volumes

Figure 4.4.1-1 shows the WGC annual total withdrawal volume (MGY), and the average daily withdrawal for the period 1998-2001. Total annual withdrawal (confined primarily to the months May-September) varied slightly ranging from a low of 10.8 MGY in 2000, to a high of 14.2 MGY in 2001. The annual withdrawals from 1998-2001 exceed the annual volume of 8.54 MGY, however, given the allowance of 100,000 gal/day over 180 days, an additional 18 MG can be withdrawn. Thus, Whitinsville Golf Course remains in compliance.

Figure 4.4.1-2 shows the average monthly withdrawal for the WGC from 1998 –2001. Average monthly water usage was highest during August (3.5 MG), followed by July (3.0 MG). Water usage drops considerably during the non-summer months.

4.4.2 Water Conservation Measures

WGC does not have any water conservation policy on file with it s Water Management Act Registration.

4.4.3 Return Flow

Water withdrawals are used to irrigate the Whitinsville Golf course. In past studies, MDEM has approximated that 50% of the water used for greens watering during the period May-September is lost from the system due to evaporation and evapotranspiration while the remaining 50% would infiltrate through the soil and eventually return as groundwater inflow to the Mumford

River. Given these approximations, shown in Figure 4.4.3-1 is the average monthly withdrawal and the estimated volume of water returned and lost from the basin.

The average (1998-2001) amount of water lost to evaporation is summarized in Table 4.4.3-1.

Table 4.4.3-1: Whitinsville Golf Course: Approximate Volume of Water Lost from the Mumford River Basin, Based on Averages for the Period 1998-2001

May	Jun	Jul	Aug	Sep	Total
0.54 MG	1.42 MG	1.48 MG	1.73 MG	0.74 MG	5.91 MG

4.5 Summary of Water Withdrawals and Losses

4.5.1 Average Annual Withdrawals

There are four water withdrawal entities in the Mumford River Basin that are currently subject to the Water Management Act. They include WWC, DWD, IFGF and the WGC. Shown in Figure 4.5.1-1 are the average annual withdrawals from 1998-2001 for each of these water users. As the figure illustrates, the major water user is WWC (70 %), followed by DWD (15%), IFGF (13%) and WGC (2%). The total average annual withdrawal for the period 1998-2001 is 656.7 MG, which is equivalent to 1.8 MGD or 2.8 cfs annually.

The same analysis was conducted using average monthly withdrawals from 1998-2001 as shown in Figure 4.5.1-2. Peak water usage occurs during July (68 MG) and June (66 MG), which is equivalent to approximately 2.2 MGD or 3.4 cfs during these months.

4.5.2 Average Annual and Monthly Loss of Water from the Mumford River Basin due to Water Withdrawals

As described above, for each water supplier or industrial user a portion of the water volume is lost from the Mumford River Basin. Losses include:

- For the Whitinsville Water Company, water is trucked from Meadow Pond to the Milford, MA Power plant. In addition, a large portion of their service territory (which includes water sold to Northbridge) has a sewer system with wastewater flowing to the Northbridge WWTP, which discharges to the Blackstone River. Infiltration and inflow to the sewer system is also carried out of the Mumford Basin. There are also customers located outside the Mumford Basin that utilize septic systems. It is assumed that approximately 50% of the outdoor water supply is lost to evaporation and evapotranspiration during May-September.
- For the Douglas Water Department, all of their service territory is located within the Mumford River Basin; however, it is assumed that approximately 50% of the outdoor water supply is lost to evaporation and evapotranspiration during May-September.
- For Interface Fabrics Group Finishing there are water losses associated with the manufacturing process, however, it was not possible to accurately quantify these losses as it is quite variable.

- For the Whitinsville Golf Course, roughly 50% of the water supply is lost to evaporation and evapotranspiration during May-September.

Shown in Table 4.5.2-1 and illustrated in Figure 4.5.2-1 is a monthly summary of the estimated volume of water lost from the Mumford River Basin from these four WMA water users.

Table 4.5.2-1: Annual and Monthly Volumes of Water Lost to Evaporation or Transported out of the Mumford River Basin due to Water Withdrawals. Averages based on the period 1998-2001. All values in MG unless otherwise noted.

Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
Whitinsville Water Company												
20.1	18.8	20.5	21.7	28.8	29.8	31.2	27.4	24.2	21.5	19.5	20.5	284.0
Douglas Water Department												
0	0	0	0	0.98	0.95	0.98	0.55	0.15	0	0	0	3.62
Interface Fabrics Group Finishing												
Unknown- in 2001, during certain months losses could be as high as 2 MG												
Whitinsville Golf Course												
0	0	0	0	0.5	1.4	1.5	1.7	0.7	0	0	0	5.9
TOTAL (in MG)												
20.4	18.8	20.5	21.7	30.28	32.15	33.68	29.65	25.05	21.5	19.5	20.5	293.41
TOTAL (in MGD)												
0.65	0.67	0.66	0.72	0.98	1.07	1.09	0.96	0.84	0.69	0.65	0.66	0.80
TOTAL (in cfs)												
1.00	1.04	1.02	1.12	1.51	1.66	1.68	1.48	1.29	1.07	1.01	1.02	1.24

As the above table shows, during the summer roughly 1.7 cfs is lost from the Mumford River Basin.

It should be noted that the above analysis is based on water users subject to the Water Management Act. There are other water users, such as residential wells, businesses, and industrial users that withdraw less than 100,000 GPD that are not required to report water usage. The cumulative effect of these other users will result in additional reductions in streamflow. It is beyond the scope of this study to estimate the contribution of these water users to reducing Mumford River flows.

5.0 National Pollutant Discharge Elimination System (NPDES) Dischargers

5.1 Background on NPDES

The National Pollutant Discharge Elimination System (NPDES) is one of the principal mechanisms for eliminating water pollution under the Federal Clean Water Act (CWA). It mandates that wastewater dischargers can discharge pollutants into surface waters only if a NPDES permit is obtained. In Massachusetts, the Environmental Protection Agency (EPA) and the Massachusetts Department of Environmental Protection (MDEP) jointly issue NPDES permits, which are typically renewed every five years. Dischargers are required to submit Discharge Monitoring Reports (DMR's) on a monthly basis to MDEP and EPA, which provide summary information such as:

- wastewater composition, including metals and other toxicants,
- for industries, their manufacturing process,
- point of discharge (river or tributary name),
- flow and frequency rates of discharge,
- period of discharge (seasonal or year-round), and
- a point of contact.

EPA uses national effluent treatment and surface water quality standards to limit the type and amount of pollutants allowed in the discharge. Average monthly and maximum daily pollutant limits are expressed numerically, in mg/l or lbs/day. Tests of effluent toxicity on the survival, growth, and reproduction of aquatic organisms are also required.

As noted above, the permittee must regularly monitor the effluent and report the results to EPA and MDEP via the DMR's. Monitoring varies with facility size, pollutant type, and the river or stream. Penalties can be levied for violating permit conditions.

Discharge limits are based on the 7Q10 flow of the river. The 7Q10 is the lowest consecutive seven-day flow that statistically occurs once every ten years. Theoretically, the magnitude of the 7Q10 is sufficient to adequately dilute the permitted level of discharged pollutants into the river.

5.2 Mumford River NPDES Dischargers

There are two major NPDES discharges in the Mumford River Basin as summarized in Table 5.2-1.

Table 5.2-1: NPDES Permit Dischargers in the Mumford River Basin

Name	Type of Discharge	Permit No.	Receiving Water	Allowable Average[26] Monthly Discharge (MGD)
East Douglas WWTP	Secondary Wastewater Effluent	MA0101095	Mumford River	Less than 0.185 MGD
Interface Fabrics Group Finishing	Fabric Mill Process Water	MA0001538	Mumford River	1.25 MGD

[26] Instantaneous discharges may exceed the limits below, which are based on an average monthly discharge.

For the two permitted facilities in the Mumford River Basin, the average daily discharge per month was obtained from the EPA's Permit Compliance System (PCS) database for the period January 1998 through December 2001. From these data, the average monthly discharge was computed and then compared to the permitted or allowable monthly discharge in MGD. Shown in Figure 5.2-1 are the average monthly daily discharges for the East Douglas WWTP (the bar charts represent the discharge data, and the line represents the permitted discharge). As the figure shows there are a few months when discharges exceed the permitted limits, however, this is likely due to infiltration and inflow into the sewer system during the spring runoff period. As will be demonstrated later, flows in the Mumford River during the runoff period are relatively high, thus it is assumed that adequate dilution of the effluent is achieved. The East Douglas WWTP is now beginning an extensive plant upgrade, which will result in a cleaner effluent discharge (Personal Communication, Therese Beaudoin, 2003).

Shown in Figures 5.2-2 are the average monthly daily discharges for the Interface Fabrics Group Finishing (IFGF) discharge for the same January 1998-December 2001 period. As the graph depicts, IFGF is well below their permitted average daily discharge rate of 1.25 MGD, which is a function of their efforts to reduce water withdrawals.

A couple of notes are worth mentioning.

- The analysis above is based on averages of four years of data. There are months when the average daily discharge exceeds the permitted daily discharge during traditionally low flow periods. For example, from January 1998 to July 1998, the East Douglas WWTP discharge exceeded the permitted discharge.
- WWTP's follow a cycle throughout the day according to water usage. Typically water usage is highest in the morning and night, while subsiding during the day. This cycling of water discharge also occurs at the East Douglas WWTP, however, there is a delay between the timing of heavy water usage and the timing of treatment/discharge to the Mumford River.

6.0 Evaluation of Hydrology (Precipitation, Reservoir Operations and Groundwater) in the Mumford River Basin

The following sections evaluate the Mumford River flow, precipitation, Manchaug/Whitin Reservoir operations, and groundwater flow.

6.1 USGS gage on the Mumford River near East Douglas, MA

Between October 1, 1939 and September 30, 1951 the United States Geological Survey (USGS) maintained a continuously recording stream gage on the Mumford River in Douglas, MA. The gage was located just upstream of Cook Bridge Dam and had a drainage area of 29.1 mi^2. Although there are only 13 years of data, an analysis of the flow data was conducted to provide insight on the Mumford River Basin hydrology.

It should be noted that basin conditions present in 1939-51 are likely different than today. Water withdrawals for public water supply were likely less, dams were probably more actively managed causing artificial flow regulation, and land use consisted of more forested areas as compared to today where there are more impervious surfaces due to development. Another unknown is whether water supplies were exported out of basin such as today. Also, as noted earlier the 16 cfs minimum flow requirement at the IFGF staff gage went into effect in 1986.

Average and Median Daily Flows- Period of Record

Shown in Figure 6.1-1 is the average annual hydrograph for the Mumford River USGS gage. This was computed by averaging flow for all Jan1st's, 2nd's, 3rd's, etc for the period of available record. On the left axis is flow (cfs) and on the right axis is the flow per square mile of drainage area (commonly expressed as cfsm- cubic feet per second per square mile). In general, low flows occur during the July-October period and high flows occur during the spring runoff period, February-April. Shown in Table 6.1-1 is a summary of the average and median monthly flows for the available period of record.

Table 6.1-1: USGS Gage on Mumford River at East Douglas, Period of Record: 10/1/39-9/30/51, Average and Median Monthly flows (in units of cfs and cfsm)

Statistic	Oct	Nov	Dec	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep
Average Monthly Flow (cfs)	27.1	31.6	39.5	49.5	60.1	80.2	65.8	62.4	48.2	26.2	24.6	24.8
Average Monthly Flow per mi^2 (cfsm)	0.93	1.09	1.36	1.70	2.07	2.76	2.26	2.14	1.66	0.90	0.84	0.85
Median Monthly Flow (cfs)	26.0	27.0	33.5	44.0	54.0	68.5	60.3	53.5	44.5	24.5	23.0	23.0
Median Monthly Flow per mi^2 (cfsm)	0.89	0.93	1.15	1.51	1.86	2.35	2.07	1.84	1.53	0.84	0.79	0.79

Notes:
1. The average monthly flow was computed by averaging all mean daily flows of each month for the period of record.
2. The drainage area at the gage is 29.1 mi^2.
3. The median monthly flow (shown above) is based on the median of all mean daily flows for each month for the period of record. As discussed below, in the USFWS' New England Regional Flow Policy, the median monthly flow is based on the median of average monthly flows. The median of the average monthly flows for August is 0.90 cfsm (as compared to 0.79 above)

The median August cfsm of 0.79 cfsm is considered high relative to other unregulated New England streams. As a point of reference, in 1981 the United States Fish and Wildlife Service (USFWS) developed an interim New England Regional Flow Policy to set minimum flows on a flow per square mile basis in the absence of site-specific data. In absence of site specific unregulated flow data, the USFWS designated the median August flow as the Aquatic Base Flow (ABF) [27] and assigned the ABF as equivalent to 0.50[28] cfsm, which is significantly less than the 0.79 cfsm (or 0.90 cfsm depending on how the median August flow is computed- see table above) August median flow for this basin. Readers should keep in mind that the period of record of the USGS gage used in the above analysis runs from 1939-1951, before the 16 cfs minimum flow requirement was established in 1986. It is assumed that the year-round minimum flow of 16 cfs established below Gilboa Dam in 1986 as part of the IFGF's NPDES permit could be based on the New England Regional Flow Policy since the drainage area at Gilboa Dam is approximately 31 mi^2 (close to 0.50 cfsm).

It is likely that the higher August monthly flows are the result of seasonal regulation at Manchaug and Whitin Reservoirs, as the reservoirs were historically drawn down in the summer to augment flows for downstream mill operations. Likewise, during March and April, when flows are typically high, the reservoirs were likely storing inflow after being fully drawn down prior to the spring runoff. An evaluation of historic water levels is provided later.

[27] The ABF is derived from the median of the mean August monthly flow records (per the New England Regional Flow Policy).
[28] The August ABF was determined by computing flow statistics of unregulated rivers with flow gages.

Average Daily Flow- Hydrographs for Individual Years

Shown in Figure 6.1-2 is a hydrograph of the mean daily flows for the period January 1, 1945 to September 30, 1945. As the graph illustrates, there was significant flow regulation during this period as the mean daily flow was pulsed on a regular basis. The pulsing varied from 30-40 cfs depending on the time of year. The cause of pulsing operations is unknown; however, it could have been the result of waterpower use or mill operations due to the magnitude of fluctuation. The magnitude of pulsing is much greater than current wastewater discharge rates.

Shown in Figure 6.1-3 is a hydrograph of mean daily flows for the period July 1, 1941 to September 30, 1941. The cumulative flow over this 92 day period was the lowest for all years examined from 1940-1951. It is interesting to note that pulsing operations are still prevalent, but the magnitude of fluctuation is on the order of 10-20 cfs (less than the above analysis). Again, it is unknown what caused the 10-20 cfs fluctuation. The average monthly flow for July, August and September 1941 were 14.6 cfs, 15.8 cfs and 14.4 cfs, respectively, much less than the average for the period of record (see Table 6.1-1).

Low Flows-Period of Record

The period of available record is too short to conduct a 7Q10 analysis (seven day consecutive low flow with a recurrence interval of 10 years). The seven consecutive day low flow was calculated from the flow records for each year. Shown in Figure 6.1-4 is the average flow over the seven day low flow period along with the start date. During February 1944 and August 1950 the average seven day flow was 7 cfs (or 0.24 cfsm). Compared to unregulated rivers in New England, this is considered to be a relatively high seven day low flow. Again, it is likely that Manchaug and Whitin Reservoirs were historically regulated to augment low flows.

6.2 United States Geological Survey Streamstats Program

The Streamstats program estimates natural flow conditions at any point in a river or tributary. The USGS has developed equations to estimate various low-flow streamflow statistics for locations on Massachusetts's streams. The equations were derived from regression analysis, which statistically relates the streamflow statistics for a group of USGS stations to physical characteristics (total length of stream, area of surficial stratified drift, mean basin slope, and hydrologic region) of the drainage basins for the stations. One of the equations can be used to estimate the 7-day, 10-year low flow (7Q10), a statistic used by the U.S. Environmental Protection Agency (EPA) and State agencies for permitting of pollutant (NPDES) discharges. Another equation estimates the August median flow, which is used by the U.S. Fish and Wildlife Service (USFWS) in New England as the minimum flow needed to maintain healthy aquatic ecosystems during low flow periods.

Output from the Streamstats program consists of the following statistics:

- 99%, 98%, 95%, 90%, 85%, 80%, 75%, 70%, 60% and 50% Annual Exceedence Flows,
- 7 day, 2 year low flow (7Q2) and 7 day, 10-year low flow (7Q10), and,
- August median flow (50% Exceedence Flow for the month).

The program also calculates prediction intervals at the 90% confidence level streamflow. It should be noted that the program does not generate average daily flow data, only low-flow statistics are provided. Thus, daily time step hydrographs or more complete flow duration curves cannot be developed. In addition, exceedence flows provided in the program outputs are based on annual flow statistics, not monthly flow statistics. Thus, the seasonal regulation of flow is not characterized in the output.

The USGS also notes that there are limitations to using the Streamstats program. They recognize that the program may be used to calculate streamflow statistics at an existing USGS gage site to determine the difference between regulated and unregulated flow conditions. They warn users not to assume that the difference between the two sets of estimates (regulated and unregulated) are equivalent to the effects of human activities on streamflow at the station because there are errors associated with both sets of estimates.

For this study, the Streamstats program was used to estimate low flow statistics (for unregulated flow) at the East Douglas USGS streamflow gage. Comparisons of low flow statistics for the retired USGS gage were then conducted as summarized in Table 6.2-1.

Table 6.2-1: Comparison of Flow Statistics from the USGS Streamstats Program- Mumford River USGS Gage

Statistic	Flow Measured at East Douglas USGS gage 1939 to 1951 (cfs)	Streamstats Estimated Flow (cfs)	90% Prediction Interval for Streamstats	
			Minimum	Maximum
Annual 99-percent duration flow	6.5	0.99	0.26	3.50
Annual 98-percent duration flow	7.5	1.30	0.37	4.38
Annual 95-percent duration flow	10.0	2.08	0.68	6.21
Annual 90-percent duration flow	15.0	3.32	1.19	9.09
Annual 85-percent duration flow	18.0	4.79	1.80	12.50
Annual 80-percent duration flow	20.0	6.32	2.47	15.96
Annual 75-percent duration flow	22.0	8.61	3.38	21.63
Annual 70-percent duration flow	24.0	11.43	4.50	28.75
Annual 60-percent duration flow	31.0	20.85	11.85	36.47
Annual 50-percent duration flow	36.0	29.73	17.78	49.53
Annual 7-day, 2-year low flow[1]	-	2.23	0.70	6.86
Annual 7-day, 10-year low flow[1]	-	0.89	0.22	3.33
August median flow	23.0	4.94	1.84	13.05

[1] Period of Record is too short to compute these low flow statistics.

In general, Streamstats[29] predicted much lower flows for all of the low flow statistics, as compared to the actual measured flows at the East Douglas USGS gage for the period of record.

[29] It should be noted that the output from the Streamstats program does not assign a period of record used in the analysis. Thus, it is uncertain if comparisons between regulated and unregulated flow conditions are based on similar periods of record. A shorter period of record could skew the results used to compute the Streamstats statistics. The USFWS recommends a minimum of 25 years of record when computing the August median flow and other flow statistics.

Measured flows are higher on an annual and perhaps seasonal basis (August median flow) compared to unregulated conditions. The reason for higher flows in the summer could be a function of the basin characteristics, precipitation or more likely releases from Manchaug and Whitin Reservoirs. These options are investigated further in this report.

6.3 Historical Operation of Manchaug and Whitin Reservoirs

Mr. Paul Lyons of IFGF provided a sporadic history of the Mumford River and the operation of Manchaug and Whitin Reservoirs (2003). Shown in Appendix D are scanned copies of the following documents:

- Letter dated October 11, 1933 from the Mumford River Reservoir Company to Mr. Winfield Schuster who was questioning low flow conditions in the Mumford River. The letter describes how water is drawn from the Mumford River Reservoir (called Whitin Reservoir today). The following quote is from this letter:

  "The drawing of water from the reservoir is controlled by a certain indenture passed in March 1854 which states that one-sixth of the water collected and reserved in the reservoir shall be drawn off in the month of July, two-sixths thereof in the month of August, two-sixths in the month of September and one-sixth in the month of October.

  At the present time the following concerns divide expense of maintenance in the following proportions:

Est. W.S. Schuster	*4/20*
W.E. Hayward & Co.	*2/20*
Schuster Woolen Company	*2/20*
Whitin Machine Works	*7/20*
James Whitin, Inc.	*3/20*
Uxbridge Worsted Co.	*1/20*
David & Brown Woolen Co.	*1/20*

  You will appreciate that this reservoir is maintained for the purpose of furnishing power to the various concerns interested.. ."

  As evidenced in this letter, Whitin Reservoir was historically operated for the sole purpose of providing power to the seven downstream manufacturers.

- Letter dated January 27, 1949 to Mr. Raymond Jacoby of the YMCA- no name was signed to the letter, but it is assumed it was from an employee of the Whitin Machine Works. The letter discusses the operation of Manchaug Reservoir as follows:

  "A record is kept in my office showing the ten year average of the height of the water in the Manchaug Reservoir. ... It is humanly impossible to foresee weather conditions so that we try to drop the water in the fall and winter, trusting to melting snow and spring rains to fill

up the reservoir. Also, if the summer is excessively dry the water in the reservoir has to be used with a consequent lowering of the water levels."

- Memo dated October 26, 1984 documenting a telephone conversation between Mr. Ball of Acheron Engineering Service and Mr. Delwin K. Barnes (who at the time was 72 years old and operated 23 dams on the Mumford River.) The memo reads:

  "*He* [this refers to a Mr. Barnes] *has a rule curve, prepared in 1936, that he uses to set water levels in the reservoirs. Starting after labor day each year he draws the Mumford Reservoir* [this is Whitin Reservoir] *approximately 10 feet and the Manchaug 6 feet by December 15th. If flow in the Mumford gets too low during the summer, he draws water from the Mumford Reservoir to maintain minimum flows in the river."*

It is assumed that the 10-year rule curve was developed by using 10 years of observed data to yield an average. In addition, although no date is assigned to the 10-year average, based on the above historical documents it likely reflects the period just before 1936. The 10-year average rule curve was used to guide operations of both impoundments during the period when the USGS gage was active.

Shown in Figure 6.3-1 and 6.3-2 are the historic 10-year average rule curves for Manchaug and Whitin Reservoirs, respectively. No benchmark or datum was assigned to the elevations provided, thus it is not possible to exactly compare today's rule curve with that used historically. However, there are some interesting findings with respect to the magnitude of drawdown historically and today. Shown in Table 6.3-1 is a comparison of the maximum drawdown for both reservoirs for the following 1) based on the historic 10-year rule curve, 2) based on the current rule curve, and 3) based on the observed reservoir elevations for the period 1999-2002.

Table 6.3-1: Maximum Drawdowns at Manchaug and Whitin Reservoirs based on Historic Rule Curve, Current Rule Curve, and Observed Elevations.

Condition	Max Drawdown at Manchaug	Max Drawdown at Whitin
Historic 10-year Average Rule Curve	5.9 feet	10.2 feet
Current Rule Curve	6.1 feet	11.5 feet
Average Levels based on the period 1999-2002	2.3 feet	5.9 feet

The question is whether the 10-year average historical rule curve was based on observed reservoir elevations and whether operators truly managed water levels according to the curve. Based on the historical documentation it appears that operators did draw Whitin Reservoir up to 10 feet and Manchaug up to 6 feet. Given this, the magnitude of drawdown for both reservoirs is considerably greater historically than the average drawdowns observed from 1999-2002. The historical drawdown at Manchaug and Whitin Reservoir is 3.6 feet and 4.3 feet (respectively) greater than current conditions. Because the historic drawdown occurred earlier (in June) and the rate of drawdown was greater compared to today, higher summer flows were likely more prevalent. The bottom line is that historically, flows in the Mumford River were likely greater during the summer period than today due to the operation of the reservoirs for the sole purpose of maintaining water in the Mumford River for the mills. In addition, due to the extent of the historical drawdown, peak flows occurring in the spring were likely lower than today.

Operation of Manchaug and Whitin Reservoirs is different today, particularly during the summer due to the competing use of water. There appears to be greater balance between recreation needs on the reservoirs and the requirement for meeting minimum flow requirements. In the past the reservoirs were operated strictly to provide water to the mills- water usage was controlled by six downstream manufacturing industries. Today, IFGF is the only manufacturing industry on the Mumford River and their operations require that a minimum flow of 16 cfs be provided at their wastewater discharge, just below Gilboa Pond. During periods of low flow in the summer, IFGF drafts water from the reservoirs to maintain 16 cfs. According to IFGF, the minimum flow requirement of 16 cfs was established in 1986.

In summary, historical flows were likely higher in the summer on the Mumford River as compared to today due to the aggressive regulation at Manchaug and Whitin Reservoirs. Today, due to recreation interests, camps, and homes lining the reservoirs, regulation requires a finer balance between reservoir uses and downstream flow needs.

6.4 Evaluation of 1999-2002 Flow, Precipitation, Reservoir Operations Data, and Groundwater

<u>Precipitation 1999-2002 relative to long term</u>

Some analysis of precipitation data was provided earlier in this report. In this section, precipitation totals from 1999-2002 are compared to the historical averages for the Whitinsville precipitation gage. The purpose of evaluating precipitation data is to determine if low flow observations in the summers of 1999-2001 are a function of reduced precipitation. Precipitation totals were evaluated throughout the year as winter and spring precipitation contributes to summer base flows. However, June-September precipitation levels may have a more direct impact on streamflow. The first step in the analysis was to compute the 10-, 25-, 50-, 75- and 90 % percentile precipitation totals using the full period of record (1874-2002) and then comparing those findings with 1999, 2000, 2001 and 2002 precipitation totals.

Shown in Figure 6.4-1 are 1999-2002 monthly precipitation totals. Also shown on the figures are the percentile rankings. In addition to these figures, shown in Table 6.4-1 is the percentile ranking of the monthly precipitation totals for the period 1999-2002 relative to the full period of record (1872-2002) for the Whitinsville precipitation gage. The table and figures were developed to illustrate the timing, severity, and longevity of recent (1999-2002) precipitation patterns. A low percentile ranking corresponds to months of low precipitation and vice versa. For example, in June 1999 a percentile ranking of 0% was computed indicating that this particular month and year represented the lowest precipitation total over the 130 year record. Alternatively, a percentile ranking of 91% in June 2000 indicates that it was one of the wetter Junes on record.

Table 6.4-1: Percentile Ranking of Monthly and Annual Precipitation for the Period 1999-2002 Relative to the Overall Period of Record (1872-2002). Whitinsville Precipitation Gage.

Month	1999	2000	2001	2002
January	95 %	54 %	11 %	24 %
February	58 %	42 %	28 %	20 %
March	76 %	67 %	96 %	62 %
April	3 %	95 %	17 %	47 %
May	38 %	48 %	28 %	92 %
June	0 %	91 %	92 %	69 %
July	62 %	55 %	80 %	12 %
August	16 %	26 %	55 %	39 %
September	98 %	53 %	40 %	62 %
October	69 %	20 %	1 %	67 %
November	24 %	58 %	2 %	79 %
December	15 %	69 %	32 %	93 %
Annual	46 %	63 %	17 %	68 %

Based on the figures and Table 6.4-1, 1999 was one of the drier summer periods with virtually no precipitation in June, slightly above median (50%) in July, and low again in August (16%). It is also interesting to note that in April and May 1999, precipitation levels were quite low – 3% in April, 38% in May- which can influence summer base flows. Thus, over a five month consecutive period from April to August 1999 precipitation totals were persistently low. During 2000, only August had lower than normal precipitation (26%), while the other winter, spring, and summer months were near or above normal. During July and August of 2002, there were also lower than normal precipitation totals that could result in lower streamflows.

In an unregulated river system, streamflow will generally increase in response to precipitation events depending on the intensity, duration and magnitude of precipitation as well as moisture conditions in the basin prior to the precipitation. The analysis of precipitation data above does not provide information on the duration of precipitation. For example, the precipitation total in a given month could be 3 inches, however, if those 3 inches all fell on August 1st, then the following 30 days would be extremely dry. Overall, the summers of 1999 and 2002 experienced lower than normal precipitation totals. While 2000 and 2001 had some months of lower than normal precipitation it did not persist for a long period of time as in 1999 and 2002. In the next section, the relationship between daily streamflow and precipitation is examined.

Precipitation and Mumford River Flow, 1999-2002

Unfortunately, the Mumford River USGS gage was inactive during the 1999-2002 period. The only available flow data is from the staff gage located below Gilboa Pond[30]. Ironically, the drainage area at the gage is approximately 31 mi^2, roughly two square miles larger than the retired USGS gage (29.1 mi^2). As noted earlier in the report, the staff gage is read daily by IFGF and instantaneous flow readings are obtained to ensure compliance with their NPDES permit. According to IFGF the gage is calibrated every five years and is accurate for measuring flows up

[30] It should be noted that the staff gage is located below the Douglas Water Department groundwater wells, but above the Douglas Water Department WWTP discharge location, thus a portion of the river flow bypasses the gage. In addition, the staff gage is above the Whitinsville Water Company withdrawals as well as above the IFGF wastewater discharge.

to 50 cfs (they estimate flows up to 100 cfs). The flow data from IFGF's gage over the period 1999-2002 was evaluated relative to precipitation as recorded in Whitinsville.

Several graphs showing the relationship between IFGF instantaneous flow measurements on the Mumford River below Gilboa Dam and daily precipitation as recorded in Whitinsville were developed as shown in Figures 6.4-2, 6.4-3, 6.4-4, and 6.4-5 for 1999-2002, respectively (keep in mind that the staff gage is accurate up to 50 cfs and between 50 and 100 cfs flows are estimated). Flows greater than 100 cfs are recorded as "100 cfs" by IFGF. All graphs were plotted on the same scale for easy comparisons.

A few observations can be gleaned from the figures. In general, after a sizeable precipitation event, the Mumford River flow increases. For example, on June 7, 2000 3.4 inches of rainfall occurred and the Mumford River flow responded by increasing from 48 cfs on June 6 to over 100 cfs on June 7. However, there are some instances when the Mumford River flow does not respond to precipitation events. For example, on August 11, 12, 13, and 14, 2001 there were 0.8, 0.19, 0.89, and 0.48 inches of rainfall, respectively. From August 11-17, 2001, the Mumford River staff gage remained constant, measuring 18 cfs. It is expected that streamflow would increase due to the magnitude and duration of precipitation. Possible reasons that the flow did not increase could be: a) the Whitinsville precipitation gage is not located above the staff gage and thus the rainfall events could have been localized (however given the duration of the rain event this does not seem likely- in fact the precipitation gage in Uxbridge had similar rainfall patterns during this period), b) the staff gage is inaccurate, or c) upstream regulation is occurring, particularly Manchaug and Whitin Reservoirs are storing runoff, however, with the intervening drainage area, it was still expected that flows would increase. Further evaluation of this storm is provided later.

A final observation from the Mumford River hydrographs is the lack of flow variability. In some instances, the flow over long periods of time remains very stable. For example, from July 6 to September 9, 1999, the Mumford River flow varied from 17 to 18 cfs, although there were several precipitation events during this period. In a natural system, flows increase and decrease based on precipitation, with much greater variability. It is hypothesized that either regulation or gage inaccuracy could be the result of limited flow variability when expected. In the next section, we evaluate the interrelationships between streamflow, precipitation and operation of Manchaug and Whitin Reservoirs.

<u>Precipitation, Mumford River Flow, Operation of Manchaug & Whitin Reservoirs</u>

IFGF provided information on the daily gate openings at Manchaug and Whitin Reservoirs for the period 1999-2002. Shown in Figures 6.4-6 through 6.4-9 are plots of Whitinsville precipitation, Mumford River Flow, and gate openings at the Manchaug and Whitin Reservoirs for the period June-September 1999-2002, respectively. Unfortunately, gate rating curves for Manchaug and Whitin Reservoirs are unavailable, otherwise discharge (in cfs) instead of gate opening would have been plotted. Keep in mind that Manchaug and Whitin Reservoirs control 6.7 mi^2 and 8.9 mi^2, respectively of the Mumford River Basin (total of 15.6 mi^2). The drainage area at the staff gage is approximately 31 mi^2, thus 50% of the drainage is controlled by these two storage reservoirs.

From June 1 through August 2, 1999, the gate openings at both reservoirs remained fixed. During July 1-4, 1999, there were four days of rain which resulted in increased Mumford River flows. For this event, flows increased due to rainfall-runoff, however, flows would have likely been even higher if Manchaug and Whitin Reservoirs were not storing inflow. As shown in Figures 3.1-4 and 3.1-8, Manchaug and Whitin Reservoirs were ponding inflow during this period as the reservoir elevations rose. The increase in Mumford River flow is likely due to rainfall-runoff on the intervening and additional portions of the basin (drainage= 15.4 mi^2) between the reservoirs and the staff gage.

As stated in the previous section, on August 11, 12, 13, and 14, 2001 there were 0.8, 0.19, 0.89, and 0.48 inches of rainfall, respectively, yet the Mumford River flow remained constant at 18 cfs. During this period, the Manchaug gate remained fixed at 2 inches. The Whitin gate was opened from 3 inches on August 11 to 4 inches from August 12-14. During this period, both reservoirs filled slightly. In all likelihood, a portion of the runoff was stored at the reservoirs. Even so, it is still expected that some increase in Mumford River flow would have occurred due to magnitude and duration of precipitation falling on the incremental drainage.

There were several instances when gate openings remained fixed, precipitation occurred, yet Mumford River flows did not increase. For example from July 15-August 2, 1999, the Mumford River flow and gate settings all remained fixed, although there were a few storm events (one with over 1.23 inches of rainfall in one day- which is a significant size rain event). Again, possible reasons for the flows not rising could be the accuracy of the staff gage, or the storm events could have been localized.

In general, Manchaug and Whitin Reservoir elevations are reduced in the summer to augment downstream flows. Gate changes are made infrequently during the summer as the graphs show, but the discharge through the gate opening is typically greater than the inflow (since the reservoir elevations drop). Because the gate openings remain relatively fixed there is little flow variability as would be seen in an unregulated river system. In some instances, when there is sizeable precipitation, the reservoirs will store water for later use as the gates again remain fixed. It is expected that if water was not drafted from storage in the summer, flows in the Mumford River would be even less than currently exists. In fact, it appears that historically Mumford River summer flows were likely even higher as the reservoirs were managed more aggressively for the mills. Both reservoirs were historically drawn down at a faster rate resulting in even greater flow in the summer. If the staff gage were accurate (although findings later in this report suggest otherwise) from 1999-2002 the Mumford River flow at the staff gage has been no less than 16 cfs. For a drainage area of 31 mi^2, this represents a flow per square mile ratio of 0.50, which is equivalent to New England Regional Policy's Aquatic Base Flow. Again, if the storage reservoirs were not regulating flows to maintain 16 cfs, flows would likely be less during several dry periods in the summer.

Flow Analysis by Mauri Pelto

Mauri Pelto, a professor at Nichols College, conducted a flow study of the Mumford River Basin during the spring of 2002 (Pelto, 2002). The purpose of the study was to evaluate flow conditions in the Mumford River mainstem and subwatersheds, and to determine differences in the magnitude of flow. Flow measurements were taken at each sampling location. The sampling locations (see Figure 6.4-10) and drainage areas are listed in Table 6.4-2.

Table 6.4-2: Flow Measurement Locations and Drainage Areas, Mumford River, MA

Basin	Drainage Area (mi^2)	Stream Order
Sutton Falls	2.75	2d
Stevens Pond Outlet	7.55	2d
Whitins Reservoir Outlet	8.95	2d
Centerville Brook	3.75	3d
Carpenter Brook	6.15	2d
Purgatory Brook	2.90	3d
Mumford-East Douglas	29.1	4^{th}
Mumford-Uxbridge	55.0	4^{th}

Synchronous[31] flow measurements were obtained at each of these sites on March 16, April 2, April 20, and May 8, 2002. The benefit of synchronous flow measurements is that changes in the timing and magnitude of flow can be more easily identified when comparing flows. In addition, the same weather conditions are present during the data collection period. Once the flows were measured they were unitized by dividing the flow by the respective drainage area to yield the flow per square mile (cfsm). Shown in Figure 6.4-11 is the flow per square mile for each sampling location for each sampling event. A few noteworthy items can be gleaned from the findings.

- Discharges from Whitin Reservoir are generally lower than the other subwatersheds as the reservoir is filling from March 16 to April 20 (Figure 3.1-11). Runoff is high on April 2 as most subwatersheds reflect a rise in flow; however, this was not the case for Whitin Reservoir outlet. On May 8, 2002 discharges from Whitin Reservoir increase which is also reflected in the high flow per square mile observed on the Mumford River at East Douglas.
- Although Manchaug Reservoir discharges were not measured in this study, as shown in Figure 3.1-7 water elevation data was provided by IFGF. During all four sampling events, Manchaug Reservoir was storing inflow as discharges were reduced. Interestingly, the same flow trend appears at the Stevens Pond outlet, which is located just below Manchaug Reservoir. Flow at the Stevens Pond outlet did not rise on April 2, 2002, while flow in the other subwatersheds did rise. During April 2 inflow was stored at Manchaug. Also, on April 12, 2002, according to the records provided by the town, Stevens Pond flashboards were installed and the low level gate was closed, thus it is assumed that discharges below the outlet were reduced further while the impoundment filled.
- Four flow measurements were obtained on the Mumford River at East Douglas (drainage area = 29.1 mi^2). Gomez and Sullivan compared the Pelto flow measurements relative to IFGF's staff gage flows on the same dates. The drainage area at the staff gage is slightly greater, 31 mi^2.

[31] Synchronous means that all flow measurements at the different streams were made within a three hour period on the same day.

Date	Measured Flow on Mumford River, 31 mi^2 (Nichols Study)	Staff Gage Flow on Mumford River, 29.1 mi^2 (IFGF)	Difference
3/16/2002	26 cfs	25 cfs	1 cfs
4/2/2002	65 cfs	40 cfs	15 cfs
4/20/2002	17 cfs	25 cfs	8 cfs
5/8/2002	61 cfs	40 cfs	19 cfs
It should be noted that although the drainage areas differ slightly there is no one tributary representing the difference in drainage area, rather it is more localized drainage.			

- Unfortunately, we have no way of confirming either of the flow measurements. However, it is suspected that the flows measured in the Nichols study are likely more accurate as actual flow metering was conducted.

<u>Groundwater Levels</u>

To further evaluate low flow claims during the last few summers, groundwater information was obtained from the USGS. There is one monitoring well (#420610071421402) located in the Mumford River Basin in Whitinsville, near the intersection of Main Street and State Road 146 (Worcester Providence Turnpike). The well water depth is measured on a monthly basis. Shown in Figure 6.4-12 is a plot of groundwater levels (in msl) for the period 1986-2002. In addition, the 25th, 50th and 75th percentile values on a monthly basis are plotted for the full period of available record. Although there are only 17 years of record, low groundwater levels (those falling below the 25th percentile) were exhibited during the years 1985, 1986, 1993, 1995, 1997, 1999 and 2001. The lowest groundwater levels occurred in July 1985 and October 1986- the lowest two on record. In most instances, lowest groundwater levels occurred in the summer or early fall, coinciding with the seasonal low surface water flow period.

It is interesting to note that the groundwater level pattern appears to change in 1993. The rate of groundwater drawdown is greater starting in 1993 and continuing through 2002 and the cycling pattern is generally repeated each year. Groundwater levels in 1993, 1995, 1997, 1999 and 2001 were at or slightly below the 10th percentile, however, after the ensuing spring, groundwater levels were replenished to near normal levels. It appears there was no long-term aquifer depletion as a result of the preceding dry years.

7.0 Streamflow Assessment, 2003

As part of this study, two staff gages were placed along the Mumford River to allow an evaluation of flow conditions from June 4, 2003 through September 15, 2003. These two gages supplemented information already available from the IFGF staff gage and an analysis of the flow data is provided in this section. It should be noted that generally the summer of 2003 was wetter than normal summer flow conditions (precipitation data is provided later in this section).

7.1 Installation of Two Staff Gages

A staff gage is essentially a long ruler placed semi-permanently in a river or impoundment and used to read water depth (also called river stage). Staff gages are used to indirectly estimate stream flow. By placing a staff gage near a section of stream for which flow measurements are collected, the relationship between stream depth and stream flow can be determined- this relationship is commonly referred to as a rating curve. Once a rating curve is established, flows can be approximated from stream depth without having to make a detailed flow measurement. Periodically, staff gages need to be recalibrated against measured flows since the streambed geometry, and thus the relationship between stream depth and flow, can change over time.

Two staff gages were installed and calibrated on the Mumford River as shown in Figure 7.1-1. The gages were located at the Potter Road Dam and the Douglas Bridge Dam, which have drainage areas of 22.6 mi^2 and 48.3 mi^2, respectively. The gages were located above and below the IFGF staff gage (31 mi^2). To develop a calibrated rating curve, the USGS typically recommends a minimum of six flow measurements (and river stages) be obtained over a range of flow conditions. Rating curves for both staff gages were developed based on five flow versus river stage measurements. Ideally, we were seeking to obtain another flow measurement at a lower flow, but hydrologic conditions (too much water) did not permit this summer.

Flow metering was conducted at cross-sections that were well confined to the river channel and relatively "clean" – no large boulders obstructing flow. Metering was conducted using a Marsh-McBirney electronic meter. It should be noted that generally the flows measured via metering are typically accurate to within 10% of the observed flow.

There are various methods of developing a rating curve. For this project two methods of estimating stream flow from gage height were compared and yielded similar results strengthening our confidence in their accuracy. A graph of gage height versus stream flow for the five measurements was made and a linear best-fit equation was developed yielding an R^2 value of 0.97 for the Potter Road Dam gage (R^2 is indicator of the strength of the relationship, an R^2=1 is a perfect fit) and 0.99 for the Douglas Bridge Dam gage. The linear method was compared to the Johnson Method. In this method gage height is plotted versus stream flow on a logarithmic scale and a linear best-fit regression is applied. The R^2 value using the Johnson Method was 0.95 (Potter Road) and 0.99 (Douglas Bridge), yielding similar results to the linear method. In the end, the linear method equation was applied since it best represents the low flow sectional control in the Mumford River. It is important to note, however, that extremely high flows (more than twice the average) may not be modeled well with the linear equation since it does not take into account channel flow or overbank flow. Shown in Figure 7.1-2 and 7.1-3 are the Potter Road and Douglas Bridge Dam rating curves. Also shown in Table 7.1-1 are the flow and staff gage heights collected to develop the rating curves.

Table 7.1-1: Potter Road Dam and Douglas Street Dam, Staff Gage Height and Flow Relationships

	Potter Road Dam Gage (22.6 mi^2)		Douglas Street Dam Gage (48.3 mi^2)	
Date	Gage Height (ft)	Flow (cfs)	Gage Height (ft)	Flow (cfs)
06/04/2003	1.04	75.3	0.77	165.5
06/19/2003	0.94	51.0	0.62	120.7
07/02/2003	0.72	24.7	0.42	55.6
07/15/2003	0.62	14.9	0.30	31.1
08/27/2003	0.61	14.6	0.24	14.7

The staff gages were installed on June 4 by Gomez and Sullivan. A temporary benchmark was surveyed at each site in case the staff gages were ever moved. Volunteers began reading the gages on a daily basis starting on June 4, continuing through September 15, 2003. As a side note, we again would like to thank Therese Beaudoin and Mike Yacino for visiting these gages site on a volunteer basis. Using the rating curve and staff gage readings, flows at Potter Road Dam and Douglas Bridge Dam were estimated. In addition, IFGF provided instantaneous flow data for their gage (31 mi^2).

7.2 Mumford Flow Findings- 2003

Hydrographs, Precipitation and Water Levels

Shown in Figure 7.2-1 are three hydrographs reflecting the instantaneous flow measurements at the Potter Road, IFGF site, and Douglas Bridge Dam staff gages. Also shown in Figure 7.2-1 are the daily precipitation totals. Shown in Figure 7.2-2 are the same three hydrographs, but plotted on a cfs per square mile (cfsm) basis. To understand upstream regulation during the sampling period, shown in Figure 7.2-3 and 7.2-4 are the Manchaug and Whitin Reservoir elevations (respectively) along with daily precipitation totals for the same period June 1-September 15, 2003.

Before interpreting the figures a few notes of caution:

1) As noted earlier all staff gage measurements were taken instantaneously. Thus, one volunteer may have read the Potter Road gage at 8:00 am, a thunderstorm may have occurred thereafter, and another volunteer may have read the Douglas Street gage later that same night. The point is that there may be some variances in the flow readings due to the timing of precipitation events and the timing of gage readings. Generally, most of the Potter and Douglas Dam measurements were made in the evening.

2) The flows presented for the Potter Road and Douglas Bridge gages are based on the best fit regression. Caution should be used when using the regression equation to estimate flows above the highest measured flow and below the lowest measured flow. The highest and lowest measured flows were as follows: Potter Road: High-75 cfs, Low-14.6 cfs and Douglas Bridge: High- 165 cfs, Low- 14.7 cfs.

3) The IFGF indicated that their gage is accurate up to 50 cfs, and flows between 50 and 100 cfs are estimated. Flows above 100 cfs are recorded as “100 cfs”.

Given these cautionary notes, a few interesting findings can be gleaned from Figure 7.2-1 as follows:

- Referring to Figures 7.2-3 and 7.2-4, during high precipitation events, Manchaug and Whitin Reservoirs stored a portion of the inflow. This was evident during larger precipitation events of 1.78 inches and 2.3 inches on June 23 and July 23, respectively. Starting around August 14, both reservoirs started to be drawn down to meet flow the 16 cfs flow requirement below Gilboa Pond.

- Mumford River flow at the Potter Road and Douglas Bridge gages responded to precipitation events resulting in increased flows as shown in Figure 7.2-1.

- Through most of June 2003, the Potter Road and Douglas Bridge flows followed similar trends of flow variability; however, the IFGF staff gage located between these gages recorded a constant flow of 50 cfs. See Note 3) above.

- Around July 23, 2003 flows at all three gages increased due to a precipitation event. Generally, flow increases as the drainage area increases, however, these conditions were not reflected at the IFGF gage. The Potter Road gage, located above the IFGF gage (and below Manchaug and Whitin Reservoirs), had a higher flow for a few days. These conditions were prevalent on September 1 as the Potter Road gage measured 46 cfs, and the Douglas gage measured 8.5 cfs. On September 2, there was 0.92 inches of precipitation which began the evening of September 1 (Whitinsville records precipitation on a 24 hour basis between roughly noon on day 1 to noon on day 2). Rationale for why the Douglas gage did not have a higher flow include: the timing of reading gages, varying precipitation totals across the basin, but most likely it is due to the lag time between Potter Road Dam and Douglas Bridge Dam. There are several large impoundments (Gilboa Pond, Lackey Pond, and Meadow Pond) between these gages and approximately 7 river miles. Routing through the reservoirs along with the distance between gages contributes to the lag time and attenuation of flow between the gages.

- There were instances when flows at Potter Road and Douglas Bridge fell below 16 cfs, the minimum flow required below Gilboa Dam. As noted above, the lowest measured flow was 14.6 and 14.7 cfs, at the Potter Road and Douglas Bridge gages, respectively. Flow measurements are typically within 10% of the observed flow. The lowest flow recorded at the IFGF staff gage was 18 cfs. In summary, there may have been a few instances when the true flow was below 16 cfs at the IFGF gage. Thus, as noted later the IFGF gage likely needs to be recalibrated. The difference in drainage area between the Potter Road and Douglas Bridge staff gages is 25.7 mi^2. As noted above, 14.6 cfs and 14.7 cfs were physically measured at the Potter Road Gage (22.6 mi^2) and Douglas Bridge gage (48.3 mi^2), yet the flow was essentially the same. Between these two staff gages is a major tributary (12.6 mi^2) in which the WWC withdrawals are located. It was expected that flows would increase downstream. Possible reasons why the flow did not increase are: impoundment evaporation, lag time and attenuation, flow measurements inaccuracy (10%), WWC water withdrawals, and/or a combination of the above.

- As noted in the previous bullet, the accuracy of the rating curves (and hence equation to convert stage to flow) declines below the lowest measured flow- around 15 cfs at both gages. There were a few occasions where the computed flow, when using the regression equation, resulted in negative flows. Obviously the flows never drop below zero, but for completeness the computed values are shown in the figures.

Additional Analysis

When site visits were conducted to measure streamflow at the Potter Road and Douglas Bridge gages, additional flow measurements were made at three other locations as follows: at the outlet of Manchaug and Whitin Reservoirs and at the outlet of Whitins Pond. The purpose for measuring the Manchaug and Whitin Reservoir discharges was these facilities have the potential to regulate a large percentage of the Mumford River flow. The Whitins Pond site was selected to determine flow in a major tributary of the Mumford River in which Whitinsville Water Company withdraws water from this subbasin. Additional flow measurements in an unregulated tributary would have been ideal as a baseline scenario to compare the other measurements (all of which were subject to regulation). Although these additional flow measurements were not part of the scope of work, it was believed that having additional information at these key locations could assist in interpreting flow conditions in the basin. Shown in Figure 7.2-5 are the flow measurements on a cfsm basis. Observations include:

- Generally, the flow trends for all gage locations were similar. Flow generally diminished over the summer observation period.

- The gate openings, discharges and discharges per square mile (cfsm) for Manchaug and Whitin Reservoirs were as follows:

	June 19	July 2	July 15	August 27
Whitin Reservoir, 8.9 mi^2	Gate open=8 in	Gate open=3 in	Gate open=3 in	Gate open=4 in
Corresponding flow & cfsm	20.6 cfs 2.3 cfsm	10.6 cfs 1.2 cfsm	4.0 cfs 0.4 cfsm	2.6 cfs 0.3 cfsm
Manchaug Reservoir, 6.7 mi^2	Gate open=3 in	Gate open=1 in	Gate open=1 in	Gate open=1 in
Corresponding flow & cfsm	11.4 cfs 1.7 cfsm	5.5 cfs 0.8 cfsm	1.7 cfs 0.3 cfsm	4.1 cfs 0.6 cfsm
Note: There may be instances where the gate opening is the same (see Manchaug on July 2, July 15 and August 27 above), however, the measured flow varied. The most likely reason for the difference is the reservoir elevation. The higher the reservoir elevation, the greater the discharge rate as there is greater pressure head on the outlet.				

The flow per square mile at Manchaug Reservoir was the highest on August 27. During this period Manchaug and Whitin Reservoirs were being drawn down to augment low mainstem flows.

- On August 27 the flow at the outlet of Whitins Pond was too low to be measured due to the low depth of water over the dam (flow measurements could not be attained).

8.0 Discussion

This study evaluates the occurrence of low flow events in the Mumford River. Human activities that could affect flow conditions in the Mumford River that were evaluated in this study include: dam operations, water withdrawals, NPDES discharges and urbanization.

Dam Operations

Information was collected on the mainstem Mumford River dams as well as other dams in the basin where the impoundment surface area exceeded 50 acres. Since not all 37 dams could be evaluated, the list was narrowed to the larger impoundments where the potential for dam regulation and downstream impacts was more likely. The goal was to determine if the regulation of these dams was contributing to low flow conditions. Unfortunately, many dam owners could not be identified, thus no information was available on if or how a dam was operated. For those facilities where owners were identified, phone interviews were conducted to obtain better insight on operations. Based on these interviews, there are five reservoirs that are regulated on a seasonal basis, meaning water levels change continuously throughout the year due to active regulation. They include: Manchaug and Whitin Reservoirs, and WWC's Reservoir Nos. 6, 5, and 4. Manchaug and Whitin Reservoirs are heavily managed by drawing down both reservoir levels in the summer and fall, and refilling in the spring. The summer/fall drawdown artificially increases flows in the Mumford River mainstem by augmenting low flows. Absent these reservoirs, flows in the Mumford River would actually be lower in the summer. During the spring runoff, flows in the Mumford River are reduced as inflow is stored in the headwater reservoirs until they are filled. A list of goals or priorities has been established for both reservoirs, with the highest priority given to maintaining a continuous flow of 16 cfs below Gilboa Pond. Cumulatively, these two reservoirs control 15.6 mi^2 of the Mumford River drainage area, or 28% of the entire basin.

With respect to Reservoir Nos. 4-6, they too are seasonally managed, but control much less of the flow in the Mumford River (the drainage area at the outlet of Reservoir No.4, the lowermost reservoir, is 1.3 mi^2.) These three reservoirs are also drawn down in the summer/fall and then refilled in the spring. However, the drawdown is used to replenish WWC's well located below Reservoir No. 4, where a significant amount of water is used to meet water supply demands in Northbridge. If these reservoirs were not seasonally operated, but were rather operated as run-of-river facilities, the impact on river flow would be worse in the summer. A portion of WWC's supply is provided by water stored from spring runoff. Without use of this storage, water used to meet demand in the summer would be obtained from groundwater.

For many of the dams, such as Stevens Pond, flashboards are removed in the late fall and then replaced after the spring runoff. Flashboard removal and installation affects flow below these dams. Flashboard removal can result in increased flows relative to natural conditions. Alternatively, flashboard installation can reduce flows below natural conditions. It is suspected that due to the timing of flashboard installation and removal, there is a period of impact on streamflows. The duration of impact will vary depending on the flashboard height, drainage area above the dam, and the impoundment size. The smaller the drainage area and impoundment surface area, the faster it will refill. Based on our interviews and site inspections in the summer

2003, these dams were operated as run of river facilities where inflow equals outflow on an instantaneous basis.

There are approximately 37 dams within the 56.6 mi^2 Mumford River watershed- or one dam for every 0.65 mi^2 of river or tributary. Collectively, the impoundments have a surface area of 1,574 acres that are subject to evaporative losses, particularly during the summer. Although only a gross estimate of water losses associated with evaporation were computed in this study, the magnitude of loss was relatively high. Since evaporative losses are the greatest during the summer, it further depletes water resources in the basin during the critical low flow period. The dams and impoundments have been present for many years, so evaporation cannot explain recent low-flow observations.

In summary, the two headwater reservoirs are currently operating in a manner that increases flow in the Mumford River mainstem in the summer. For the remaining dams on the Mumford River, most are abandoned and thus it was assumed that they were not regulated. Under this assumption, inflows to these facilities would closely match outflow. As noted in the recommendations, additional information is needed on the abandoned dams to clarify operations and to determine if they are contributing to low flow conditions.

<u>Water Withdrawals</u>
There are four water users that are registered with the DEP under the Water Management Act including Whitinsville Water Company (WWC), Douglas Water Department (DWD), Interface Fabrics Group Finishing (IFGF) and the Whitinsville Golf Course (WGC). The major water user is WWC (70 %), followed by DWD (15%), IFGF (13%) and WGC (2%). The total average annual withdrawal for the period 1998-2001 is 656.7 MG, which is equivalent to 1.8 MGD or 2.8 cfs annually.

WWC withdraws water primarily from two wells located below the IFGF staff gage in a tributary to the Mumford River Basin (below the IFGF staff gage). Water usage for WWC has increased by 25% over the period 1998-2001 (but by 9% from 1996 to 2002). If water use trends continue at the current pace, WWC may exceed their allowable water withdrawal before February 2004. In 2001, the total annual withdrawal was equivalent to 484 MG or 2.0 cfs, while in July 2001, water withdrawals were 47 MG or 2.3 cfs.

WWC supplies water to customers within the Mumford River Basin, and also sells water to the Northbridge Water Company, which includes service areas outside the Mumford River Basin. Withdrawals are also occasionally trucked to the Milford, MA Power plant, generally during the summer months. Water was trucked during two of those four years examined in this study. A large portion of the WWC service territory has a sewer system with wastewater transferred to the Northbridge WWTP, which is located on the Blackstone River. Infiltration and inflow to the sewer system is also carried out of the Mumford Basin. The bottom line is that a portion of WWC's water withdrawals are lost to out-of-basin transfers, storm and sanitary sewer systems, and evaporation/evapotranspiration from outdoor summer water use. Water withdrawals reduce the magnitude of flow in the tributary entering the Mumford River at Whitins Pond (Northbridge). The drainage area of the Mumford River, just upstream of the Whitins Pond outlet is 34.7 mi^2. The drainage area is relatively large compared to the volume of water withdrawn by WWC. In short, WWC withdrawals reduce tributary flow in the Whitins Pond drainage area (12.6 mi^2)- in fact on August 27, 2003 flows at the Whitins Pond outlet were too low to measure. It should also be noted that WWC has three storage reservoirs to maintain water supplies, which are beneficial to meet summer peak demands. Absent these reservoirs, there would likely be a greater impact on streamflow during the summer.

DWD withdraws groundwater from four wells located within the Centerville and Riddle Brook subwatersheds of the Mumford River. DWD water usage has increased by 4% over the last four years. In 2001 average annual withdrawals were 103 MG or 0.4 cfs. Peak summer withdrawals in 2001 were equivalent to approximately 0.5 cfs. All of DWD's service territory is located in the Mumford River Basin. In addition, the East Douglas sewer system services an area, and discharges water only within, the watershed. Thus, there are no out of basin water transfers. Between the withdrawal locations and the East Douglas WWTP return flow, there is an approximately 0.85 mile segment of the Mumford River that is bypassed. Water withdrawals will reduce the magnitude of flow in the 0.85 mile reach of the Mumford River. The drainage area of the Mumford River just upstream of the withdrawal locations is 24.1 mi^2.

IFGF withdrawals have steadily decreased over time, dropping by 27% between 1998 and 2001. They have implemented several water conservation measures to help reduce water demands. In 2001, annual water withdrawals were 73 MG or 0.3 cfs (summer withdrawals were also around 0.3 cfs). According to IFGF, there is little water consumed in their processing. Most processing water is returned to the Mumford River via their treatment plant, which is located just downstream of Gilboa Pond- only a short reach of the river is impacted.

WGC also withdraws water from the Mumford Basin during the golf season. Their total withdrawal in 2001 was 14.2 MG over 180 days, with peak usage occurring in August 3.3 MGD (0.16 cfs). It is estimated that half of WGC's withdrawals are lost to evaporation and evapotranspiration.

In summary, in 2001 water users registered under the WMA collectively withdrew 674 MG from the Mumford River Basin (2.85 cfs). Water withdrawals contribute to low flow conditions in the Mumford River, particularly during the summer when water usage is the greatest. For example, the collective August withdrawal (all four users) was 64.9 MG or 3.24 cfs. Keep in mind that there are other water users, such as residential wells, businesses, and industrial users that are not subject to the WMA (which only regulates withdrawals of greater than 100,000 GPD). The cumulative effect of these other users will result in additional reductions in streamflow.

Land Use

There is limited information to evaluate the impacts of land use changes (particularly increased development) on streamflow. Land use trends in the Mumford River watershed have changed between 1971 and 1999. Between this period, forest lands have been reduced by 8.6%, while residential land use has increased by 7.9 %. No long term flow data is available during this period to evaluate long term trends potentially associated with land use changes. In other studies in Massachusetts (Parker River Low Flow Study), where there was a long-term flow monitoring gage, peak flow and base flow trends were evaluated. As a general rule, increased urbanization and impervious surface, lead to more rapid runoff from storm events. Runoff is captured in storm sewer systems and discharged much more quickly to a river. Absent impervious surfaces, runoff will infiltrate soils to the point of complete saturation before land surface runoff occurs. Infiltrated water eventually returns as base flow to a river. Depending on the extent of urbanization, there can be a noticeable trend in the magnitude of peak flows before and after urbanization. Similarly, as the area of impervious surfaces increase, base flow, which is a key component of the river flow in the summer, can be depleted.

Conclusion

Based on the above analysis, it is difficult to pin point cause(s) of extreme low flow in the Mumford River during the period 1999-2001, particularly in the areas identified by Mr. Yacino, which is primarily in the Douglas area. Water withdrawals contribute to low flows, as do the operation of some dams. In addition, during the summers of 1999 and 2002 precipitation levels were low, resulting in lower streamflow. The bottom line is that the operation of Manchaug and Whitin Reservoirs provides higher summer flows in the Mumford River than would exist absent the manipulation of these two reservoirs. The August cfsm using historic flow data was 0.79 cfsm or 23 cfs. In comparison to unregulated rivers in New England, this flow is considered to be relatively high. In addition, although the IFGF gage requires recalibration, the minimum flow requirement is 16 cfs below Gilboa Pond, which is equivalent to roughly 0.5 cfsm- the USFWS Aquatic Base Flow.

One of the missing components of this study is historic streamflow data. The only flow data in recent years was the IFGF staff gage, which appears to be inaccurate at times and requires relocation and recalibration. In our opinion if the IFGF staff gage was relocated and recalibrated, IFGF could better manage releases from the Manchaug and Whitin Reservoirs to ensure a continuous 16 cfs in Douglas. Flow management would also be enhanced if gate opening/discharge rating curves were established at Manchaug and Whitin Reservoir outlets. It is suspected that flows may have dropped below 16 cfs in the past, as evidenced in our flow measurements in 2003. If there is support to further investigate low flow conditions, more continuously recording flow gages may be needed in the Mumford River and unregulated subwatersheds. Gages would be placed in areas where regulation is already suspected as identified in this study. If gages were installed the cause and effect of human disturbances on streamflow is likely to be more obvious. Based on an analysis of all of the available information, it is hypothesized that streamflows have not been below natural flow levels (but may have been below the required 16 cfs due to gage inaccuracy) in the Mumford River at least down to Douglas portion of the mainstem (except during periods when Manchaug and Whitin Reservoirs were retaining inflow- mostly during the spring season).

As the synchronous flow measurements collected by Gomez and Sullivan on August 27, 2003 indicated the intervening flow between the Potter Road and Douglas Bridge gages was minimal (0.1 cfs over an incremental drainage area of 25.7 mi^2 or less than 0.01 cfsm). Within this subwatershed there is a main tributary which contains the WWC water withdrawals. During the summer months the water lost from this subwatershed was estimated at 16.2 MG in July (the other summer months had lower estimated water losses). This volume of water is equivalent to 0.8 cfs in July, thus although WWC contributes to low flow conditions, there are many other factors that play a role including precipitation, impoundment evaporative losses and reservoir regulation.

9.0 Recommendations

General recommendations were developed to address issues that were encountered during the study process.

- It is recommended that the Massachusetts Department of Environmental Protection (MDEP) improve efforts to verify the accuracy of all data reported on Public Water Supply Annual Statistical and Registered & Permitted Withdrawals Annual Reports as part of the Water Management Act. For example, the state has established triggers for unaccounted for water or gpcd use that would require further research. One example is Whitinsville Water Company reporting residential water usage as 26 gpcd. This water use rate is unrealistically low relative to the trigger levels of 70-80 gpcd. Follow-up is needed to verify the accuracy of these numbers.

- Hard copies of the Public Water Supply Annual Statistical Reports and Registered & Permitted Withdrawals Annual Reports were obtained by visiting the MDEP offices. The data from these reports were then keypunched into spreadsheets such that various graphs could be developed to evaluate the data. It would be extremely beneficial if water users were able to enter the data requested on the forms via an on-line reporting system. Although it would take time for the state to develop an on-line system that contained essentially the same information as the Public Water Supply and Registered & Permitted Reports, it would greatly improve water management on a basin-wide scale. The system would have endless abilities to analyze the data entered. Some capabilities of such a database include:

    - develop various plots of a single water user,
    - develop various plots of multiple water users in the same basin to determine basin wide water withdrawals on an annual and monthly basis,
    - quickly determine if a water user is in compliance with permitted and registered withdrawals,
    - flag excessively high or low unaccounted-for-water or residential water use consumption,
    - evaluate basin wide water use trends by evaluating all users in the same basin
    - evaluate out of basin water transfers
    - as more data is obtained long-term water use trends could be examined
    - reduce excessive paperwork
    - the data could be readily used to forecast future demands.

    In summary, a computerized database would help in managing overall water uses and would reduce the time needed to keypunch data. Listed above are only a handful of possibilities that could be created to evaluate water data and result in better management of the state's water resources.

Dams

- Historically, the Mumford River was heavily used to provide power and processing water to the numerous mills lining the river corridor. Virtually none of the mills operate in this manner any longer, yet the remnants of this water-intensive manufacturing period remain. There are roughly 37 dams in the basin, with several located on the Mumford River mainstem. In our limited research, we could not locate many of the dam owners and thus we assumed that the dam was abandoned. It is recommended that further investigation into dam ownership be undertaken for two purposes. First, many of the dams have outlived their intended purpose, and may have safety issues. We received from the Massachusetts Office of Dam Safety a list of the dams in the Mumford River Basin. The dam owners, as provided by the State, were in many cases incorrect or outdated. In addition, during our site visit we located two other dams on the mainstem that are currently not in the State's database (it should be noted that these dams may not fall under the State's jurisdiction). Typically, the State conducts dam safety inspections every few years, depending on the hazard classification. High hazard dams are inspected more regularly compared to low hazard dams. If there is a safety issue with a given dam, the State will need to identify the correct dam owner to ensure that measures are taken to bring the dam into compliance. As a side note, it is our understanding that future dam safety inspections, which have historically been conducted by the state, will be the responsibility of a licensed registered professional engineer hired by the dam owner.

The second purpose for identifying the dam owner is to obtain further information on the specific operation of the facility. It was beyond our scope to spend considerable time trying to locate the owner and obtain this information. Efforts were made to identify owners by communicating with other identified dam owners and visiting town offices, but in many cases the owner could not be identified. Having been to many of the dams, it appears that most are operated as run-of-river facilities due to the lack of gate structures needed to control flow. However, by contacting the owner, this assumption could be validated.

- As stated earlier there is roughly one dam for every mile of the Mumford River. The adverse impact of dams on fish, wildlife, wetlands, Threatened and Endangered species, water quality and other environmental resources is well documented in the literature. Given that many of the Mumford River dams have outlived their intended purpose, consideration should be given to potential dam removals. It is recognized that removing a dam is not a simple process as there are numerous issues that must be addressed in a feasibility study before a potential removal is considered. Examples include a) what would the pros and cons of removal be on wetlands, wildlife, water quality and fish passage?, b) is the impoundment filled with sediment and does the sediment contain pollutants?, and c) is there infrastructure such as a bridge above the dam that could be subjected to scour and erosion after removal. This is just a short list of a host of issues associated with dam removal. In addition, due to the age of many of the dams, they have considerable historical significance- in fact many were likely constructed of hand placed stone. The dams have also become part of the "natural" landscape in their communities, thus there are aesthetic and socioeconomic resources to address. Working with the State's dam removal program, River Restore, it is recommended that an initial study be undertaken to identify mainstem Mumford River dams that, if removed, would provide significant ecological benefit. Based on a desktop exercise and site visits, the pros and cons of potential removal could be identified. If one or more dams are possible candidates for removal, then a feasibility study should be conducted to evaluate the costs and benefits of removal as well as the potential positive or negative impacts.

- There are currently no gate rating curves that have been confirmed at the outlets of Manchaug and Whitin Reservoirs. IFGF records gate openings and reservoir elevations on a daily basis. Discharges from both dams are a function of the gate opening and head. Collectively, the two reservoirs control 15.6 mi^2 of the Mumford River drainage basin or 27%. Because the reservoirs control a major portion of the flow in the river, it is recommended that a gage be placed just downstream of Manchaug and Whitin Reservoirs. The recording gage would measure river stage, which could then be converted to flow via a rating curve. Over time as additional gate openings and headwater elevations are recorded, they could be compared to the measured flow such that a reliable rating curve can be developed.

- It is recommended that IFGF strive to manage releases from Manchaug and Whitin Reservoirs to mimic a more natural response to precipitation events. In many instances, gate openings were maintained at the same setting for several weeks although precipitation events may have occurred during the same period. Ideally, gate adjustments should be made on a daily basis to mimic the basin's natural streamflow response to precipitation events. There is extensive literature and documentation regarding the benefits of natural flow variability on aquatic resources and the riparian environment. It is also recognized that there needs to be a balance between summer recreation interests and providing a natural flow regime below the reservoirs.

- Many of the smaller dams (such as Sutton Falls Dam, Stevens Dam) install flashboards just after the spring runoff and remove them in the fall. Once flashboards are affixed to the spillway crest, there may be several hours or days before the impoundment fills (depending on the impoundment size, drainage area and flashboard height) to the flashboard crest. While the impoundment fills, no flow is conveyed below the dam unless a low level gate is opened. In some instances flow can be reduced to only leakage, which negatively impacts downstream aquatic resources. It is recommended that a continuous minimum flow be provided below these dams when the flashboards are reinstalled. A couple of the flashboards could be notched or removed to maintain a continuous flow while the impoundment fills. Once filled, the notch could be removed such that flows are spilled over the flashboards. It is beyond the scope of this study to determine the magnitude of minimum flow, however, absent any detailed information a flow equivalent to 0.5 cfsm (based on the New England Regional Flow Policy), or inflow, whichever is less, should be provided. It is recognized that most dams in the Mumford River Basin are under the State jurisdiction, however, the state has no authority to mandate minimum flows except through NPDES permits, WMA permits, or as part of a Section 401 Water Quality Certificate. For a majority of the abandoned dams no NPDES, WMA or Water Quality Certificate is required. In these instances, maintaining minimum flows would be conducted on a voluntary basis.

- It is recommended that all dams in the Mumford River Basin that regulate discharges should be operated to maintain continuous seasonal minimum flows throughout the year. As noted above, most dams under the State's jurisdiction are not necessarily required to maintain a continuous minimum flow. Absent any detailed studies, we recommended defaulting to at least the seasonal minimum flows set forth in the USFWS New England Regional Flow Policy (1981) as follows.

Period	Fall/Winter (Oct-Mar)	Spring (Apr)	Summer (May-Sept)
Flow per square mile	1.0 cfsm	4.0 cfsm for the entire applicable spawning and incubation periods	0.5 cfsm as derived from the median August Flow

Maintaining continuous seasonal minimum flows will help ensure that aquatic resources in the riverine reaches below the dams are protected. Obviously, for Manchaug and Whitin Reservoirs these flow recommendations could result in lowering the impoundments in the summer, which could create issues with lakefront homeowners and recreation interests- a balancing of recreation and aquatic resources would need further investigation. Thus, some negotiation regarding releases may be required for Manchaug and Whitin Reservoirs.

- Aldrich Pond, which is part of the Sutton Falls Campground, is a headwater tributary to Manchaug Reservoir. As noted earlier, Ms. Linda Nelson indicated that in 2002 algae and other pollutants were discharged from Aldrich Pond at the conclusion of the camping season when the gate was opened to lower the pond level. Ms. Nelson indicated that the large influx of pollutants compromised the water quality of Manchaug Reservoir. Some testing indicated that large amounts of phosphorus are entering Manchaug Reservoir from Sutton Falls Dam. Large amounts of watermeal were also detected by the MA Department of Environmental Protection. It is recommended that the source causing pollutants to enter the stream system above Aldrich Pond be evaluated and controlled. Aside from the water quality issue, in lieu of fully opening the gate to lower Aldrich Pond in 3-5 days, it is recommended that the discharge be conveyed slowly in an effort to reduce the influx of pollutants. A second issue is the magnitude of flow below the dam during the refill period. The operator indicated that the gate is closed and inflow is stored during the spring to refill the pond. It is recommended that the gate be opened to provide a minimum flow below the dam during refill.

Water Supplies

- The Whitinsville Water Company (WWC) water distribution system services the town of Northbridge, a portion of which is located outside the Mumford River Basin, and currently there is no method of tracking how much water is discharged outside the Mumford watershed. In addition, there is a sewer system in Northbridge within the Mumford basin that collects effluent from a portion (roughly 60%) of the Whitinsville service territory. The sewer system eventually drains to the Northbridge WWTP, which discharges into the Blackstone River. Again, there is no method to track the amount of water transferred out of basin. Earlier in this report, an estimate of water lost from the Mumford River was provided; however, it was based on some gross assumptions. Recognizing that we do not have any detailed background on the Northbridge sewer system, if possible, it would be ideal to meter (or at least better estimate) the amount of water leaving the Mumford River system to the Northbridge WWTP. The bottom line is that more accurate information is needed on the amount of water leaving the Mumford River Basin.

- Both Whitinsville Water Company (WWC) and Douglas Water Department (DWD) mail information pamphlets outlining water conservation tips to their customers in an effort to decrease water consumption. For WWC, ordinances are in place to implement mandatory outside water restrictions in times of severe drought. DWD also has a drought management plan that implements various measures depending on water availability and use. It is recommended that WWC and DWD take measures to further conserve water. This will require increased public outreach and education to end-users of the need for water conservation particularly during critical periods. There are a host of measures that could be implemented to reduce water usage such as: retrofitting shower heads, low flush toilets, water efficient washers, etc- in fact many of these measures may have already been implemented by the public water suppliers. The critical period typically occurs during the summer, when lawn watering occurs. As noted earlier, DWD has taken steps to conserve water by banning any future irrigation systems as of December 2001. If not already implemented, it is recommended that mandatory odd-even lawn water restrictions be required to help alleviate water usage in the summer. In some areas of the country, water users are asked to follow an every-third-day (at most) watering schedule for lawns, and water only between 8 p.m. and 8 a.m. to reduce water lost to evaporation.

  We have no information on the cost charged by the water suppliers for water. If not already implemented, as an incentive to reduce summer water usage, water suppliers could charge a higher fee when water users exceed a certain threshold (increasing block rate). DWD already has a progressive rate system, where heavy water users pay more.

- Most low flow events occur in the summer when water supply demands are the highest, resulting in even greater stress on already low flowing rivers. For WWC and DWD, the ratio of peak demand to average daily demand was computed to determine the magnitude of summer usage. The peak factors were 1.74 for WWC and 1.90 for DWD. Through aggressive water conservation measures and public outreach, WWC and DWD should strive to limit this ratio to 1.5, as well as cap gallons per capita per day use to 65. In addition, DWD should limit unaccounted for water to 10% or less if possible. Leak detection surveys and repairs should be conducted on an annual basis, if possible.

- On an annual basis, WWC's water use has been increasing steadily, up 25% from 1998 to 2001 (9% between 1996 and 2002). If water usage continues to increase, WWC may exceed the Water Management Act allowable volumes. DWD water use has also been rising, but at a slower pace than WWC. Regardless, it is recommended that WWC and DWD project future water supply needs in the years 2005, 2010 and 2020 based on population growth. The Commonwealth of Massachusetts has methods for forecasting future demand, which should be implemented for these suppliers. The concern is that water withdrawals will continue to increase, resulting in even greater stress on the Mumford River flows and tributaries. In the case of WWC, a portion of future withdrawals will likely continue to be transferred to the Northbridge WWTP for treatment. In the case of DWD, it is unknown if the East Douglas WWTP could absorb the projected increase in water use. By forecasting future usage, the town of Douglas can plan in advance any potential upgrades to their WWTP to handle future loads.

- As noted earlier, WWC reported residential water use as 28-32 gpcd. This is an unrealistically low residential water usage, and it is recommended that WWC evaluate how this value is computed such that more accurate reporting is provided.

- It is recommended that water trucked from Meadow Pond to the Milford, MA Power plant be ceased, as it results in a direct loss of water from the Mumford River Basin during low flow periods.

- Although not a large user, the Whitinsville Golf Club does not have any water conservation policy in place. It is recommended that a water conservation plan or drought management plan be developed in consultation with the state. Measures in the plan should become part of their Water Management Act registration. At the very least, it is recommended that golf course irrigation occur during the evening or night when evaporation is the lowest. In addition, during critically dry periods, it is recommended that watering be localized to only putting greens.

- Lastly, IFGF has taken great strides to reduce water consumption. It is recommended that IFGF continue their efforts to reduce water consumption in the future. IFGF should also consider separating their stormwater from their wastewater.

Flow

- Based on the study findings, extremely low flows on the Mumford River could not be verified by our findings. In fact, without the flow augmentation provided by Whitin and Manchaug Reservoirs, summer flows would be even lower- closer to natural conditions. The USGS Streamstats analysis indicated that under an unregulated river system Mumford River flows would be well below current regulated levels in the summer. The August median flow as computed from the retired USGS gage was 23 cfs as compared to 5 cfs based on Streamstats. In addition, flows of at least 16 cfs must be maintained just below Gilboa Dam throughout the year, which is equivalent to a flow per square mile of approximately 0.5 cfsm. This flow rate is typically acceptable to the resource agencies managing aquatic resources as it is equivalent to the recommendations set forth by the US Fish and Wildlife Service in their New England Regional Policy (1981).

- There are times when the flows measured at the IFGF staff gage are not balanced with flow readings at Potter Road Dam and Douglas Dam. In some instances, the flows were greater at Potter Road Dam as compared to the IFGF gage even though Potter Road is upstream. It is recommended that the IFGF gage be recalibrated and relocated. It is suspected that flows have dropped below 16 cfs in the past, as evidenced by Gomez and Sullivan measurements. Typically, gages are placed at control structures such as on an abutment of a dam. The existing gage consists of a measuring tape affixed to a stake placed directly in the river channel. The stake could be subject to movement due to icing or excessively high flows. A change in the stake position could result in an inaccurate gage reading and hence flow. In addition, channel geometry at the gage site could change resulting in a change/accuracy of the rating curve. We recommend affixing a commonly used USGS style staff gage to the

Gilboa Pond Dam abutment and periodically collect flow measurements below the dam to verify the gage accuracy and to develop a more accurate rating curve.

- Although not highly recommended, if there remains a concern regarding low flows caused by regulation then additional flow monitoring may be required. Much of our analysis of pre-2003 data was based on the IFGF staff gage, which appears to be inaccurate at times. Currently, three staff gages are available, but they must be read manually to obtain instantaneous flow levels. In addition, two of the gages installed as part of this study were read by volunteers, which have been discontinued. Since rating curves have already been developed for these three staff gages[32], continuous water level recorders could be placed at all three sites and river stages could be converted to flow via the rating curves. Having long-term flow data for these three stations would help in evaluating flow trends. In addition, flow data in unregulated subwatersheds would provide baseline conditions and could be used for comparison purposes.

Development

- To help limit the amount of runoff entering stormwater systems, residential homeowners should be encouraged to utilize cisterns and rain barrels to collect and store rainwater for outdoor use. (1,000 square feet of roof can collect 420 gallons of water from 1 inch of rain. The water collected in a cistern, can be siphoned off to water gardens or wash cars).

- Between 1971 and 1999, residential land use in the Mumford River Basin has increased by 7.9%, while forest land as decreased by 8.6%. Development in the basin will impact the timing and magnitude of Mumford River streamflows. To limit the impact of future development, it is recommended that local planning boards carefully scrutinize new applications for large-scale developments (i.e., large subdivisions, golf courses, etc.). Planning Boards may wish to consider implementing a water bank or otherwise mandate mitigation measures to off-set the impacts of future developments to assure these do not place further demands on the water systems and exacerbate low-flow conditions. Other techniques for reducing environmental impacts of development are to prevent removal of topsoil from sites, limit the area disturbed on building sites, limit the area of lawn that is allowed on lots, and promotion of alternative lawn and landscape designs. These steps reduce the amount of water used in landscape establishment and maintenance. If not already implemented towns should consider a ban on automated sprinkler systems or mandating water sensors that prevent the sprinkler system from activating when it is raining. Studies show that homes with automatic sprinklers use up to 30% more outside water than homes with manual systems (City of Boulder, 2003). Also, installation of drip irrigation systems for non-turf areas can increase water use efficiency up to 75%. In addition, planning boards should ensure that land located above aquifer recharge areas remains undeveloped (i.e., land conservation). Preventing development within these areas will allow adequate precipitation infiltration into the land and subsequent recharge of major groundwater aquifers.

[32] The IFGF staff gage rating curve needs to be refined.

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